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Project NY 420 001-2
Technical Memorandum M-066

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TEST OF ANCHORS FOR MOORINGS AND GROUND TACKLE DESIGN

10 June 1953
Revised 1 September 1957

U. S. NAVAL CIVIL ENGINEERING
RESEARCH AND EVALUATION
LABORATORY
PORT HUENEME, CALIFORNIA

NOX

Project NY 420 001-2
Technical Memorandum M-066

TEST OF ANCHORS FOR MOORINGS AND GROUND TACKLE DESIGN

10 June 1953
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OBJECT OF PROJECT

To design and develop mooring anchors with improved stability and greater holding-power than existing anchors obtain in sand, mud, and clay bottoms.

OBJECT OF SUBPROJECT

To determine the behavior and holding-power of the test anchors in a sand bottom.

OBJECT OF THIS REPORT

To describe the test results of newly designed concrete-steel, concrete-mushroom, and wedge-shaped anchors, and to compare the behavior and holding-power of those anchors with those of the present type of stockless anchors, with and without stabilizers.

RESULTS

Stability of the anchors was improved by adding stabilizers. The addition of stabilizers increased the holding-power of each anchor and also provided a more uniform holding-power. Test results indicated that a "fluke-angle" of 35 degrees produced the greatest holding-power for anchors tested in a sand bottom.

U. S. NAVAL CIVIL ENGINEERING
Research and Evaluation
LABORATORY
Port Hueneme, California

Project NY 420 001-2
Technical Memorandum M-066

TEST OF ANCHORS FOR MOORINGS AND GROUND TACKLE DESIGN

10 June 1953
Revised 1 September 1957

R. C. Towne

SUMMARY

Tests were conducted

The U. S. Naval Civil Engineering Research and Evaluation Laboratory conducted tests in a sand bottom to determine the behavior and holding-power of the newly designed concrete-steel, concrete-mushroom, and wedge-shaped anchors, and to compare the behavior and holding-power of these anchors with those of the present type of stockless anchors, with and without stabilizers.

Tests ~~conducted~~ on Navy stockless anchors of 1500, 5000, 6000, 7000, 9000, 10,000, 13,000, 15,000, 18,000, 20,000, 25,000, and 30,000 lb proved that rotation of the anchors could be minimized by the addition of stabilizers. The length and size of stabilizers, designed by the Bureau of Yards and Docks, varied with each weight of anchor.

The correct stabilizer was found for the concrete-steel anchor, and tests showed that this anchor has a greater holding-power in sand than does a Navy stockless anchor of a comparable weight, the wedge-shap anchor, or the mushroom-type anchor.

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The addition of stabilizers increased the holding-power of the anchor in every instance and also provided a more uniform holding-power.

Results of tests to determine the correct "fluke-angle" for all anchors under test indicated that an angle of 35 degrees produced the greatest holding-power in a sand bottom.

PREFACE

All stockless anchors have the disadvantage of rotational instability when dragged through the ground by a very strong chain pull. This instability creates a holding-power which fluctuates from a maximum to a minimum in a short distance. This tendency to rotate has been studied and reported in a paper by Moll, in 1918, entitled "The Evolution of the Ship's Anchor and the Fundamentals of the Construction of Modern Anchors," and in 1931 in "Reports and Memoranda No. 1449," published by the British Air Ministry. From these studies and others made at the Naval Advanced Base Proving Ground, Davisville, Rhode Island, December 16, 1944, it was apparent that the stockless anchor possessed no stabilizing component which would prevent rotation about the shank. The equilibrium of the anchor could be upset by any of several factors, such as different density of soils at one fluke relative to the other, unsymmetry of the anchor, or uneven ground-surface conditions.

It was to improve the efficiency of the present anchors by increasing their holding-power and stability, to develop more suitable design criteria, and to minimize the use of scarce and critical material during times of emergency that these tests were made.

Second Edition, Revised
1 September 1957

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INTRODUCTION

The Bureau of Yards and Docks utilizes anchors in the installation of moorings for all types of vessels and of ground tackle for floating drydocks, cranes, and other similar types of craft. Following model studies and allied research conducted in the Bureau to improve the mooring anchor, the U. S. Naval Civil Engineering Research and Evaluation Laboratory, at Port Hueneme, California, conducted full-scale studies and investigations to determine the behavior and holding-power of the newly-designed concrete-steel anchor, concrete-mushroom anchor, and wedge-shaped anchor, and to compare their behavior and holding-power with those of the present stockless anchors, with and without stabilizers. This project, NY 420 001-2, was divided into four phases as follows: (1) rotational-stability tests in sand to stabilize the anchors, (2) holding-power tests of stabilized anchors in a sand bottom, (3) holding-power tests of stabilized anchors in a mud bottom, and (4) holding-power tests of stabilized anchors in a clay bottom.

At present, the holding-power of Navy stockless anchors is computed by a formula established by model studies.[1] The holding-power is based on the anchor fluke area, but for convenience it is expressed in terms of anchor weight: 7.1 times the weight of the anchor in air for standard stockless anchors in a sand bottom, as stated in BUDOCKS manual, Moorings, NAVDOCKS P-259. The function of the anchor weight, in reality, is to provide the anchor with sufficient strength and also to assist it to overcome the vertical component of the soil reaction against the penetration of the anchor.

This report contains a description of the tests in both the first and second phases, together with the results and conclusions. Additional comparative tests were made with several commercial anchors manufactured by R. S. Danforth, of Berkeley, California.

ANCHOR-TESTING APPARATUS

Prior to these tests, the available information on anchor tests had been obtained from model studies or from limited full-scale tests in which the anchor was not visible to the observers; therefore, an anchor-testing apparatus (shown in Figure 1) was constructed to permit visual observation of the characteristics of the anchors under a strong chain pull.

The apparatus consists of a 20-ft gage railway, 300 ft in length, the open end of which is 100 ft from mean low tide; a 20,000-lb gross load, traveling instrument car; and a winch mounted on a stationary platform at the inshore end. The instrument car was fabricated to simulate the movement of a ship in dragging its anchor and to carry a 600,000-lb capacity towing dynamometer or a 400,000-lb capacity electrical dynamometer to measure the holding-power of the anchors. The power necessary to pull the car and to drag the anchors was provided by a model BU-140 Skagit winch (shown in Figure 2). One end of the car was joined to the winch by a four- or six-part, 1-3/8 in., 6 by 19, plow-steel, hemp-center wire rope; and the test anchors were connected to the opposite end of the car by a 2-3/4 in. cast-steel anchor chain. The winch and six-part line are capable of imparting loads to the anchors of approximately one million pounds.

The area in which the anchors were pulled is flooded each night by the ocean tide, and, in addition, the anchors could be initially set under water by using a pontoon warping tug.

SOIL-PENETRATION TESTS

Pipe-penetration resistance tests of the soil through which the anchors would be dragged were made before and during the tests.

The equipment for obtaining the data consisted of a 3-in. diameter pipe, used as the resistance pile; a drop hammer; and a winch for raising the drop hammer (shown in Figure 3). The 3-in. pipe was capped at the bottom end and fabricated in 10-ft sections. The 300-lb drop hammer (shown in Figure 4) was mounted in 30-ft leads, and its fall was automatically controlled at 24 in. by means of a special tripping device (shown in Figure 5). The two-drum winch used to raise the hammer was driven by a 75-hp Jaeger engine. The apparatus was mounted on an LVT-3 to facilitate movement across the sand.

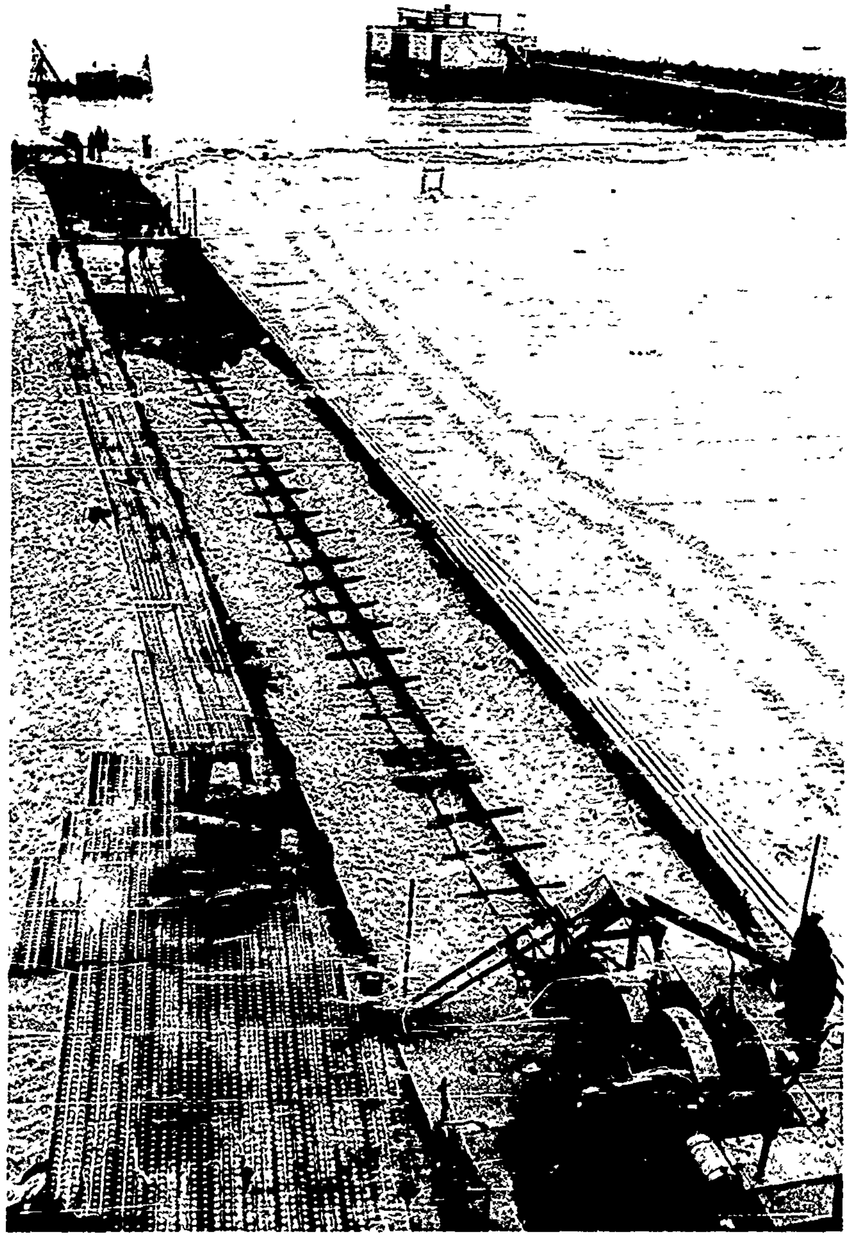


Figure 1. Anchor-testing apparatus.

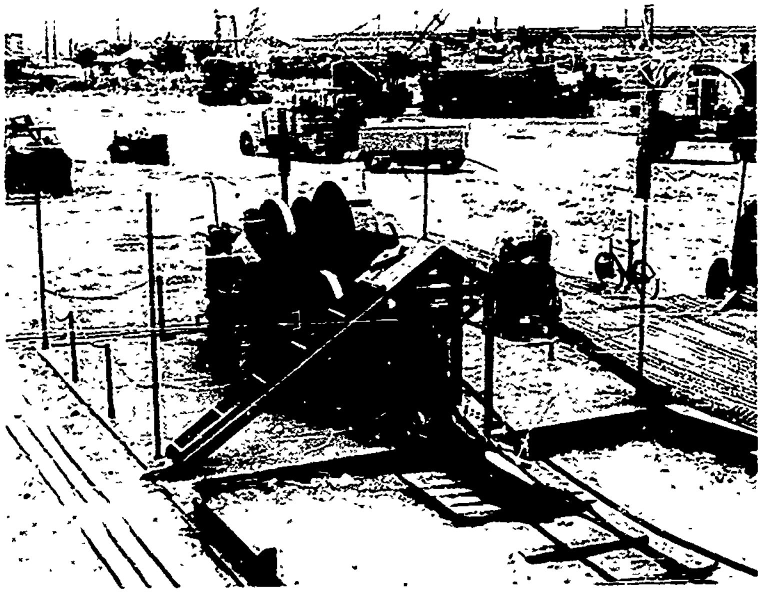


Figure 2. Skagit winch, model [illegible]J-140.

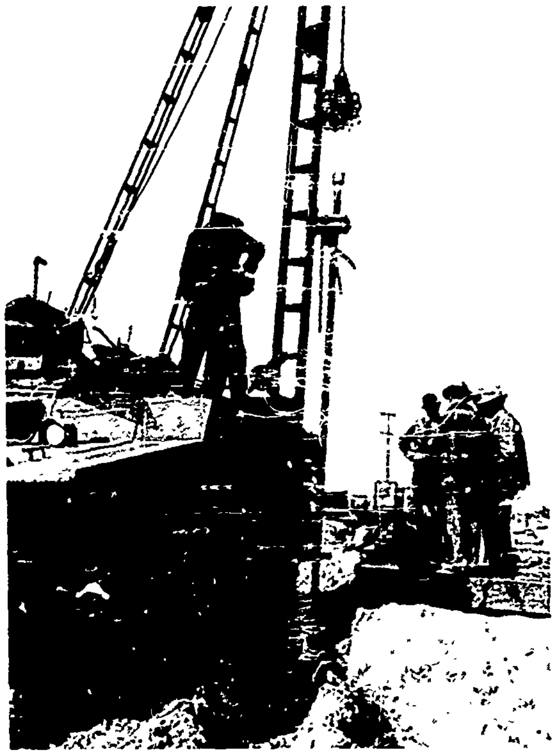


Figure 3. Soil penetration-resistance test equipment.

Figure 4. Drop hammer mounted in leads.

Figure 5. Tripping device for releasing drop hammer.

The penetration-resistance test data listing the undisturbed soil tests taken before the start of the anchor tests and the disturbed soil tests taken during the anchor tests are given in Appendix A.

A mechanical analysis of the soil at the test site showed 95-percent sand particles, 92 percent of which was finer than 0.6 mm, the remainder being less than 2.0 mm in size.

ROTATIONAL STABILITY TESTS

The stabilizers used on the Navy stockless anchors were fabricated in accordance with BUDOCKS drawing no. 412,751.[2] The purpose of the stabilizer is to counteract the rotational torque characteristic in the Navy stockless anchor. This rotational torque causes the anchors to rotate (shown in Figures 6, 6 (a) and 6 (b), respectively).

Stabilization is accomplished by the reaction of the stabilizer to dynamic earth pressures produced by the anchor rotating under a strong chain pull (shown in Figure 7). The maximum amount that a stabilized anchor was permitted to rotate during the tests was 10 degrees from the horizontal. This amount of rotation was required to permit the stabilizers to react to the earth pressures.

In order to expedite changing the stabilizer length during the tests, the stabilizers were constructed longer than necessary and then shortened in decrements of approximately 3 in. until the correct length was obtained. Six pulls were established as the minimum number of tests to be made with the stabilized anchor to evaluate the effectiveness of the stabilizer. All rotational-stability tests were conducted with zero-degree chain angles.

ANCHOR CHAIN TESTS

Test pulls of the anchor chain alone were conducted to determine the resistance of the chain dragging through the sand bottom. The average holding-power of 210 ft of 2-3/4 in. anchor chain is 23.3 kips, and, for 180-ft of 1-1/2 in. anchor chain, 6.0 kips.

The anchor chain is useful primarily in flattening the angle at the anchor shackle and in absorbing shocks as the catenary dips and straightens.

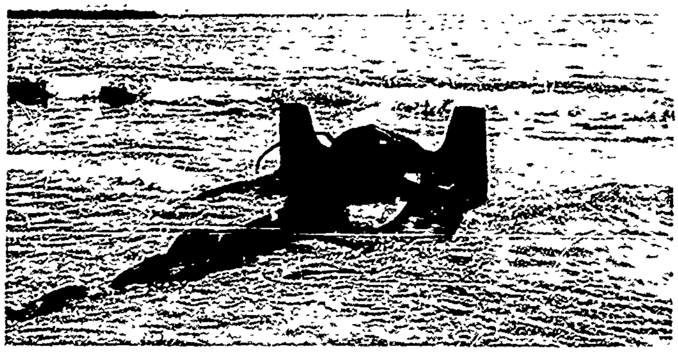


Figure 6. Rotational instability of Navy stockless anchors.

Figure 6 (a). Anchor flat on beach.

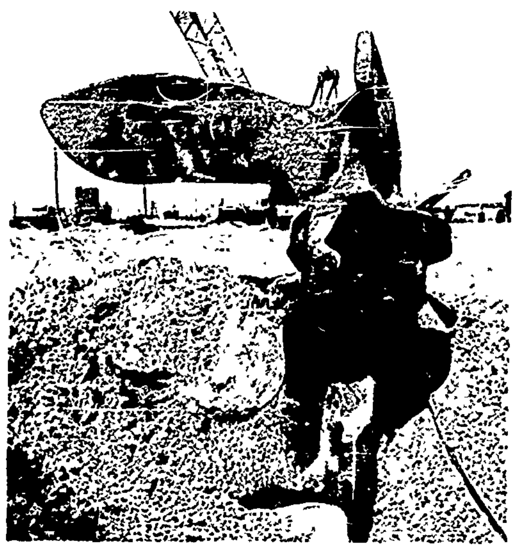


Figure 6 (b). Anchor at point of 90-degree rotation from horizontal.

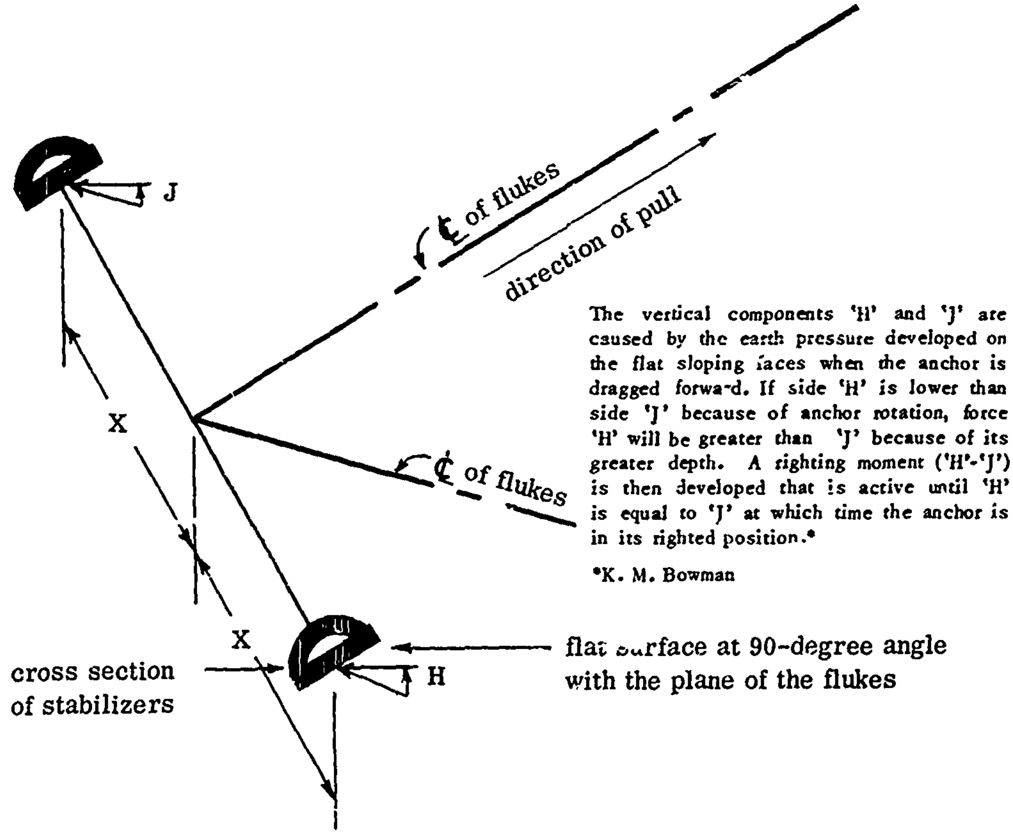


Figure 7. Schematic of stabilizer action.

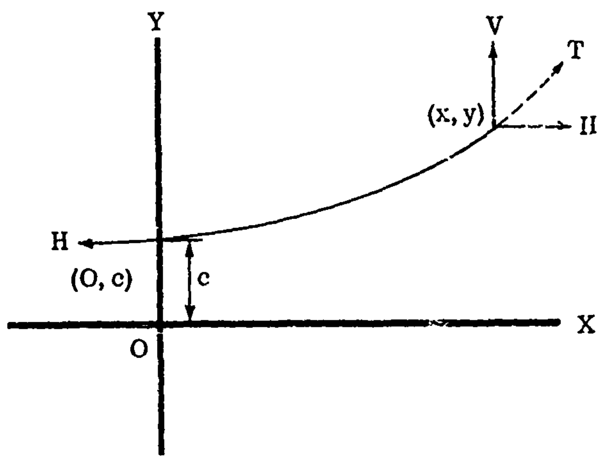


Figure 8. Catenary curve.

The anchor chain used in the rotational-stability tests was of sufficient length to establish a zero-degree angle between the chain and the sand bottom at the anchor shackle during the period of maximum holding-power.

The chain lengths were obtained by relations as follows (shown in Figure 8):[3]

At point (x, y)

$$V = ws$$

$$H = wc$$

$$T = wy$$

Equations of a catenary

$$y^2 = s^2 + c^2$$

$$y = c \cosh \frac{x}{c}$$

$$s = c \sinh \frac{x}{c}$$

H = horizontal force at point (x, y)

V = vertical force at point (x, y)

T = axial tension at point (x, y)

s = length of curve from point (0, c) to point (x, y)

w = weight of chord per unit length

An example of the calculations for computing the chain length for an 18,000-lb anchor is given in Appendix B.

CONCRETE-STEEL ANCHOR

The newly-designed, concrete-steel, 7500-lb anchor, furnished by BUDOCKS for the tests, is most adaptable for use as a mooring anchor. The anchor has a single rectangular fluke constructed of concrete encased on the top and sides with a steel plate. The shank, constructed of steel, is fixed at a 28-degree angle with the fluke.

This anchor was first tested using steel stabilizers 28-in. long, 12-in. wide, and 1-in. thick, which were constructed in accordance with BUDOCKS drawing no. 355,036.

Because of the configuration of the anchor, it was necessary to determine its reaction in the event it was dropped on the bottom of the ocean in an inverted position. Therefore, the anchor was placed upside down on the beach (shown in Figure 9), and dragged through the sand. The distance required for the anchor to right itself and reach its maximum holding-power under this condition was recorded.

Thirty-two test pulls were made using the BUDOCKS designed stabilizer. In nine instances, the anchor righted itself in an average distance of 133 feet. The average maximum holding-power for these nine tests was 155 kips. During the remaining 23 tests, the anchor did not right itself, but an average holding-power of 102.3 kips was recorded.

Following these tests, a lighter and shorter steel stabilizer, 24-in. long, 12-in. wide, and 1/2-in. thick, also furnished by BUDOCKS, was tested.

Six pulls were made with anchor equipped with this stabilizer. Three tests were started with the anchor right side up, and three tests with the anchor upside down. The anchor righted itself once in the three upside-down tests. The average maximum holding-power of the anchor, for the tests in which it righted itself, was 136.5 kips, and, for the remainder of the tests, the average maximum holding-power was 119.2 kips.

Subsequent tests were made on the concrete-steel anchor using adjustable stabilizers, 30-in. long, 1-in. thick, and 12-in. wide, constructed according to BUDOCKS drawing no. 461,597.[4] The adjustable stabilizers' design permitted the face of the stabilizers to be rotated in relation to the line of pull on the anchor.

The anchor was pulled with the 30-in. long stabilizers (shown in Figure 10), set at angles of 90, 87, 85, 84, 82, 80, and 75 degrees to the horizontal, with six pulls being made at each angle setting.

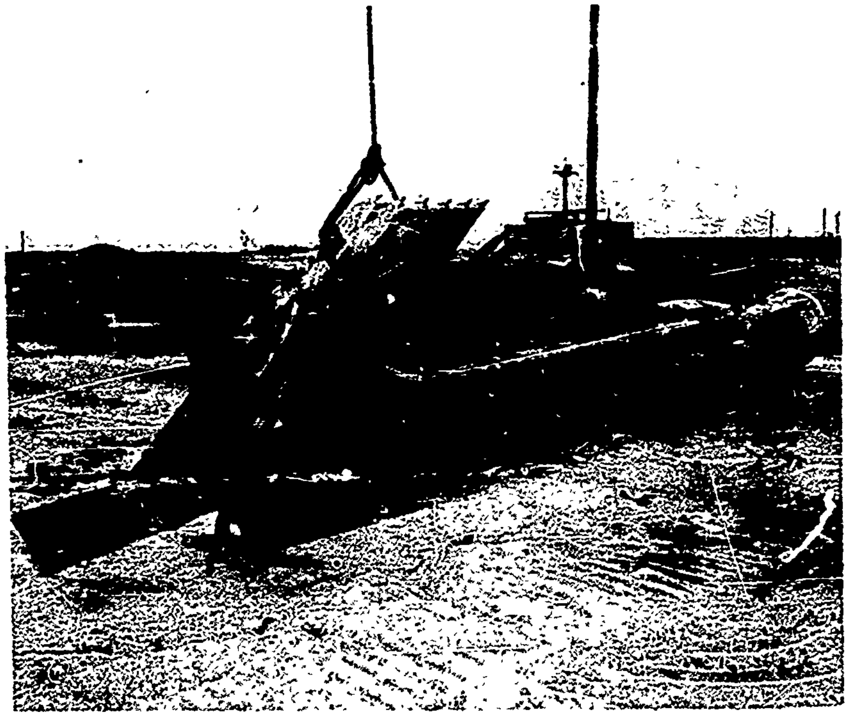
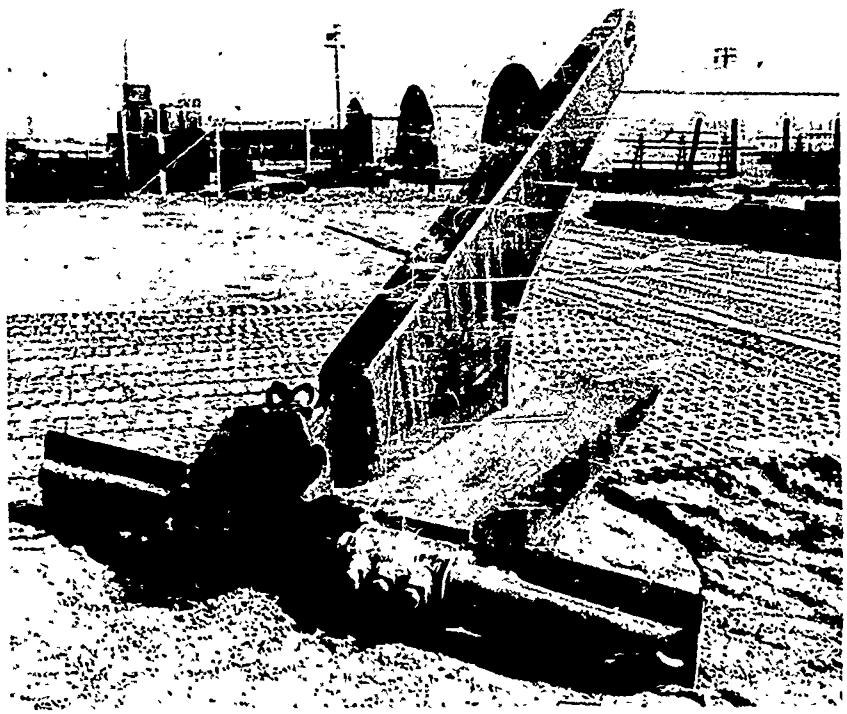


Figure 9. 7500-lb concrete anchor with 28-in. long stabilizers.



Figu 10. 7500-lb concrete-steel anchor with adjustable stabilizers.

The best results were obtained when the stabilizers were set at an angle of 85 degrees, the average maximum holding-power for this setting being 130.4 kips. The results of the six pulls made for each angle setting of the adjustable stabilizer are shown in Figure 11. Selection of the most suitable stabilizer angle was based upon the average maximum holding-power and the shortest distance required to right the anchor. A graph of one test pull made on the concrete-steel anchor with the adjustable stabilizers set at an 85-degree angle is shown in Figure 12. The anchor was placed upside down at the beginning of the pull and righted itself after having been dragged 65 feet. Results of the tests are given in Table I.

75-LB FORE-AND-AFT ANCHOR

The 75-lb fore-and-aft anchor, shown in Figure 13, was designed by BUDOCKS for possible utilization as a pontoon-causeway mooring anchor.

It is composed of fore-and-aft flukes, a shank, and stabilizers. The smaller fore-fluke is located near the towing shackle, and the larger aft, or main, fluke is located near the stabilizers. Both flukes are fabricated from 5/16-in. thick steel plate. The shank, constructed of two pieces of 1-1/4 in. diameter steel pipe, is fixed at an angle of 30 degrees from the flukes. The stabilizers consist of two 1-1/4 in. diameter pipes, each 15 in. in length, with a 5/16-in. thick triangular steel plate welded to the outer end of each pipe.

The anchor was pulled six times and the average holding-power after 50 ft of drag was 700 pounds. The anchor was unstable and rotated a maximum of 60 degrees from the horizontal during the tests. The base and altitude dimensions of the triangular plate stabilizers were increased from 5 in. to 7 inches, and the anchor was pulled six more times. No rotation was observed during these latter test pulls, and the average holding-power after 50 ft of drag was 733 pounds. The maximum ratio of holding-power to anchor weight was 11 to 1.

NAVY STOCKLESS ANCHORS

The Navy utilizes three types of stockless anchors: the standard, the Dunn, and the Baldt. These anchors are all-steel anchors consisting principally of the shanks, trunnions, crowns, and flukes, the crown

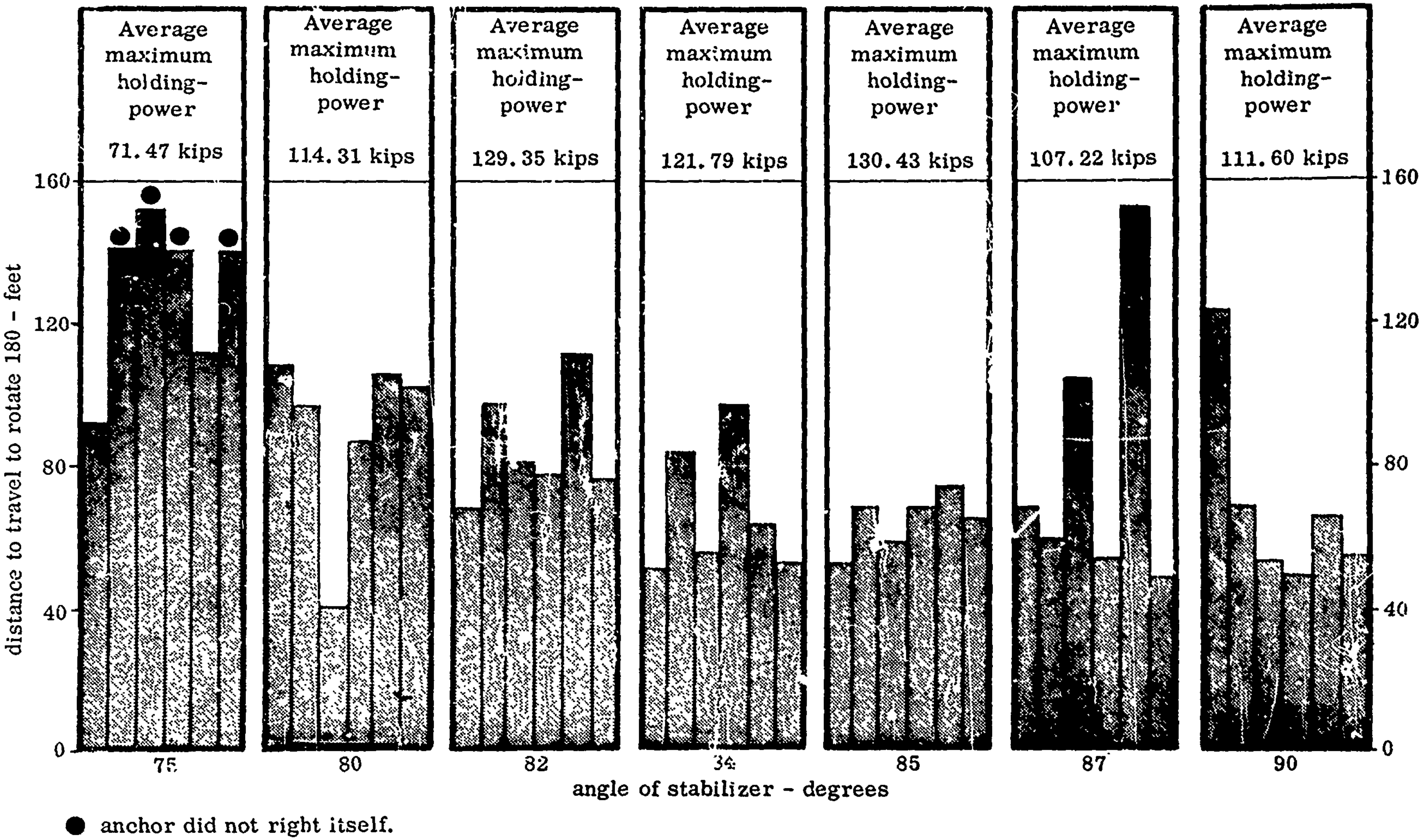


Figure 11. Results of test pulls on 7500-lb concrete-steel anchor with adjustable stabilizers. Anchor was placed upside down on beach at start of pull.

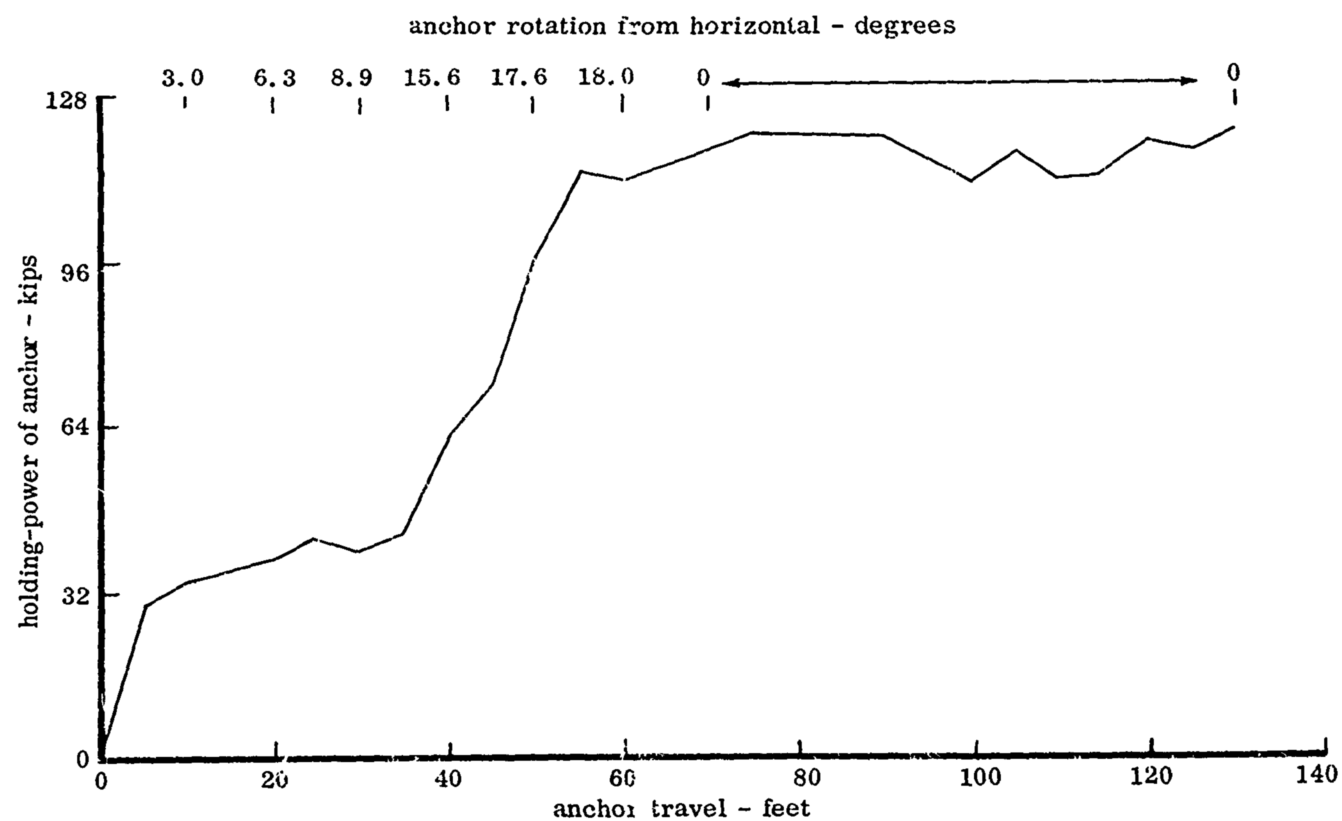


Figure 12. Graph of one test pull on a 7500-lb concrete-steel anchor with adjustable stabilizers set at 85-degree angle. Anchor inverted at start of test.

TABLE I. Holding-Power Data of Steel Anchors Tested on the Beach.

Type	wt-lb	Initial "fluke-angle"	Average holding-power w/o stabilizers, length of drag: 50 ft	100 ft	150 ft	Stabilizers (in.): width	thickness	length	Final "fluke-angle"	Average holding-power w/stabilizers, length of drag: 50 ft	100 ft	150 ft
Dunn	1500	41	19,200	22,400	22,500	6	1/2	21	35	26,100	29,300	29,500
Standard	5000	43	42,300	36,300	40,000	16	1/2	42	33	54,600	56,000	55,000
Dunn	6000	48*	35,200	32,300	36,600	16	1/2	42	35	58,600	58,300	55,800
Dunn	7000	45	68,800	48,300	60,000	16	1/2	24	45	58,300	76,000	71,000
Standard	9000	42	53,300	44,600	44,700	-	-	-	-	--	--	--
Standard	9000	35	63,000	28,000	45,000	-	-	-	-	--	--	--
Dunn	10000	47	75,300	41,000	40,500	19	3/4	36	33	90,900	92,000	90,000
Standard	13000	48*	108,200	96,000	76,000	19	3/4	42	32	111,200	141,700	154,500
Dunn	15000	42	110,900	103,000	106,900	-	-	-	-	--	--	--
Standard	[illegible]	49*	11[illegible],100	59,000	78,500	21	1	45	34	175,500	189,800	218,800
Standard	20000	45*	155,5[illegible]0	148,000	122,000	-	-	-	-	--	--	--
Standard	25000	41*	190,800	207,200	200,000	21	1	48	32	186,200	263,000	281,600
Dunn	30000	49*	192,800	100,30[illegible]	196,600	23	1	50	34	151,300	228,200	230,300
Fore and Aft	75	30	--	--	--	7	5/16	7	30	733	775	825
Concrete Steel	7500	28	--	--	--	-	-	-	28	107,600	115,500	120,000
Admiralty	5000	50	--	--	--	5	round	62	50	32,400	32,700	33,000
Baldt	5000	52	43,500	36,300	39,200	16	1/2	42	34	54,700	55,900	56,200
Baldt	9000	40	62,800	54,000	53,600	-	-	-	-	--	--	--
Danforth	80	37	--	--	--	1-1/8	round	12	37	16,700	15,300	15,300
Danforth, two in parallel	80	37	--	--	--	1-1/8	round	12	37	25,500	19,000	19,000
Danforth	2510	32	--	--	--	4-1/2	round	51-1/2	32	60,000	69,300	70,000
Danforth	2770	34	--	--	--	4-1/2	round	51-1/2	34	102,500	104,000	105,000
Danforth	3380	35	--	--	--	4-1/2	round	51-1/2	35	97,500	101,300	109,600
Danforth	10000	34	--	--	--	5-1/2	round	62-1/2	34	124,000	134,200	138,800
Danforth	12000	36	--	--	--	10	round	82	36	216,000	274,700	272,000
Danforth	85	37	--	--	--	1-1/8	round	12	37	8,300	7,600	7,600

* Initial "fluke-angle" had to be reduced to permit the anchor to dig into sand.

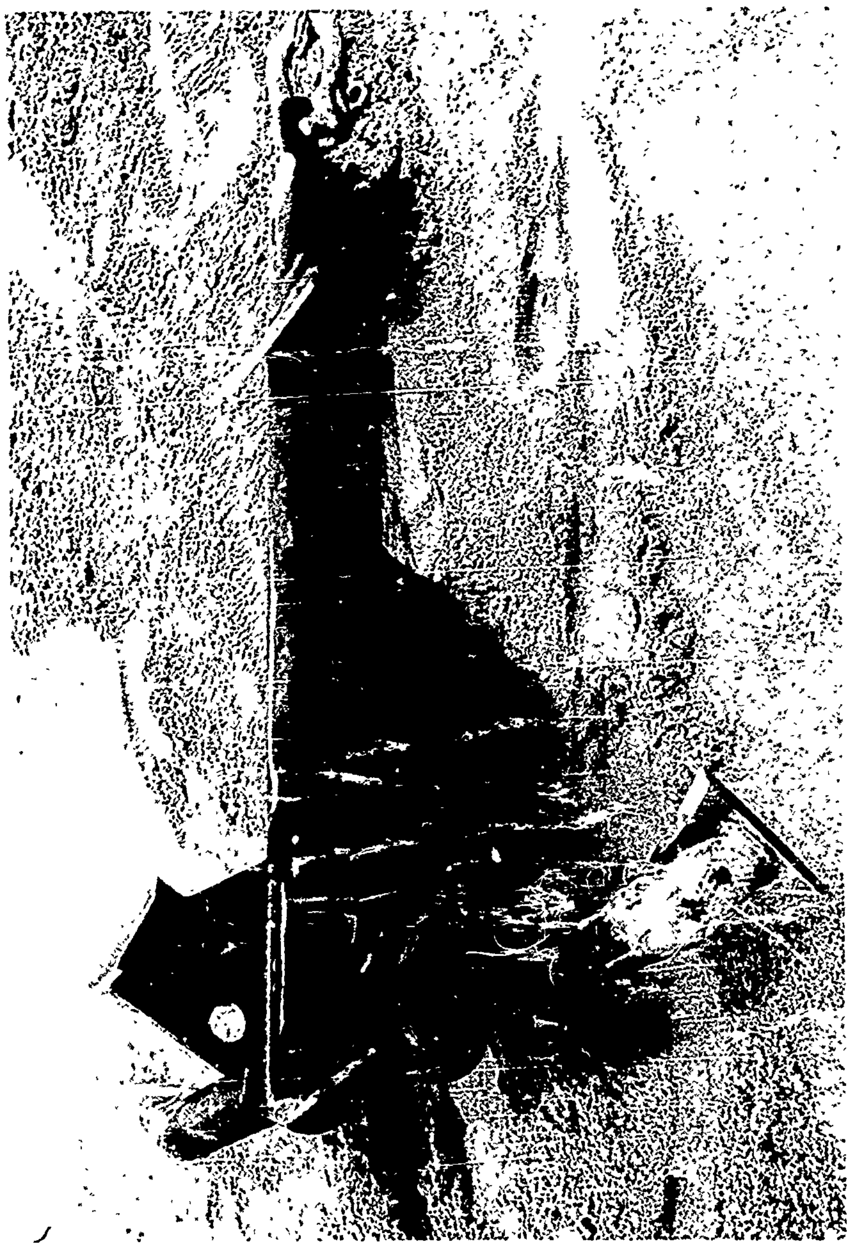


Figure 13. BUDOCKS designed 75-lb fore-and-aft anchor.

being the large, round ball located midway between the flukes and enclosing the trunnion, which secures the shank to the crown and flukes. The primary difference between the Dunn and standard anchors is in the design of the trunnion, that for the Dunn being a round ball, and for the standard, a cylinder. BUDOCKS drawing no. 164,615[5] and Pittsburg Steel Foundry sheet no. X-4741[6] give the details of these anchors. The cylinder-shaped trunnion provides a more uniform "fluke-angle" than does the ball-shaped trunnion. The Baldt anchor, which has a ball-shaped trunnion, has smaller flukes for similar weight anchors than do either of the other two types.

In addition to the stabilizing tests, tests were conducted to determine the comparative holding-power of the three types of anchors. Tests of six stockless anchors of each of four weight groups, 6000, 10,000, 20,000, and 30,000 pounds, were made without stabilizers to find the least stable anchor of each group. The selected anchors were tested to determine if stabilizers would adequately correct their instability. The anchors were chosen at random from Navy stock at Port Hueneme. Because of the limited supply of available anchors, it was necessary in the 6000-, 10,000-, and 20,000-lb weight groups to substitute 5000-, 9000-, and 18,000-lb anchors to complete the required number for the tests.

Each of the six anchors in each weight group was pulled six times, and the anchors that rotated the greatest number of degrees from the horizontal were selected as the least stable. Each test pull began with the anchor laid flat on the sand.

The degrees of rotation and the distance of anchor travel for each anchor of the 6000-lb through the 30,000-lb weight groups are shown in Figures 14, 15, 16, and 17.

Each of the least stable anchors was stabilized as described in the rotational-stability tests section and was similar in appearance to the Navy standard anchor (shown in Figure 18). The stabilized anchor of each weight group was pulled six times to determine the effect of the stabilizer and the average holding-power.

Table I gives the holding-power of the unstabilized anchors, the initial "fluke-angle" of each anchor, the size of the stabilizers required to stabilize the anchors, and the "fluke-angle" and holding-power of the stabilized anchors. Graphs of the performance of the 6000-, 10,000-, 18,000-, and 30,000-lb anchors with and without

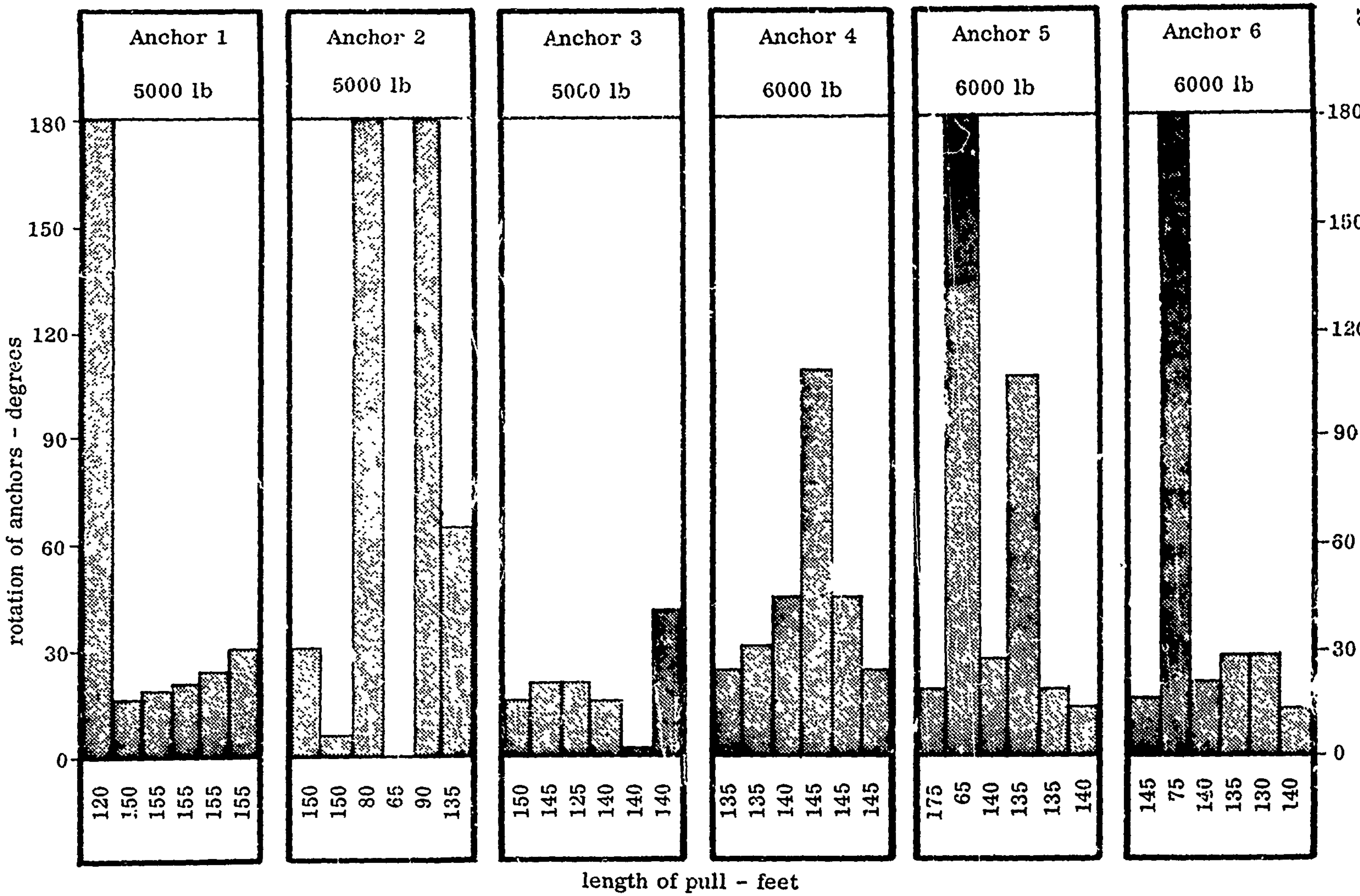


Figure 14. Rotational-stability tests for 5000-lb and 6000-lb stockless anchors.

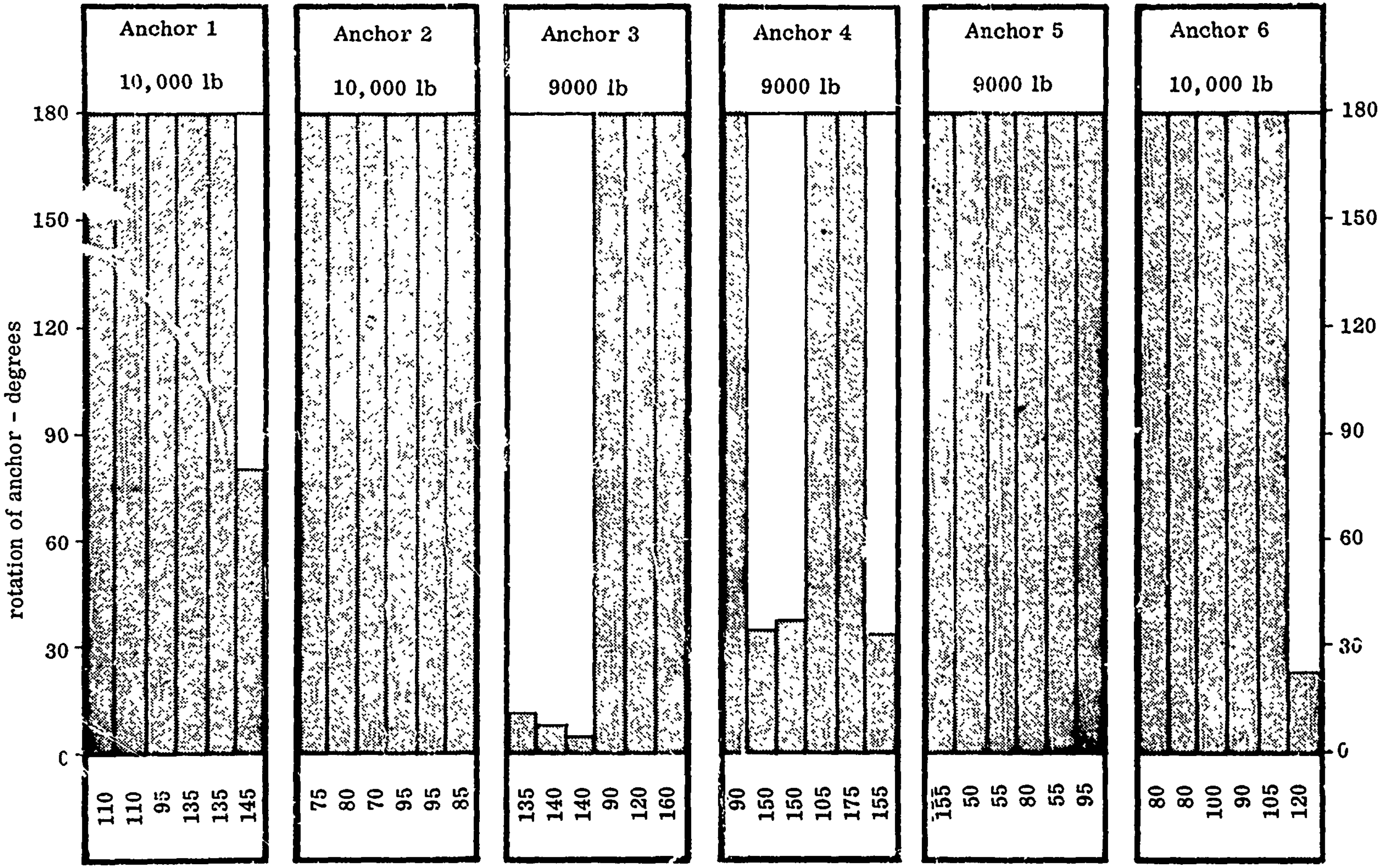


Figure 15. Rotational-stability tests for 9000-lb and 10,000-lb stockless anchors.

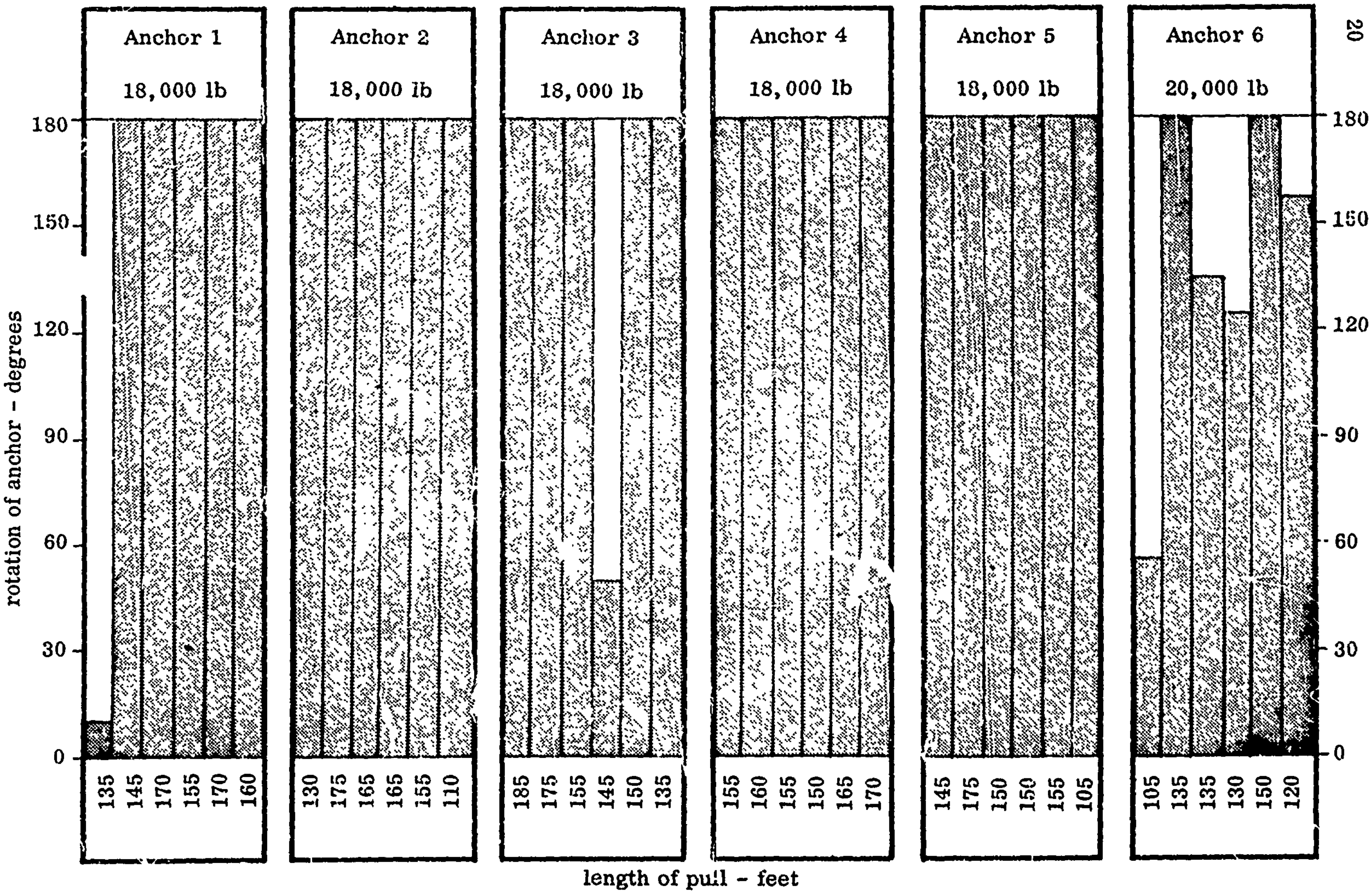


Figure 16. Rotational-stability tests for 18,000-lb and 20,000-lb stockless anchors.

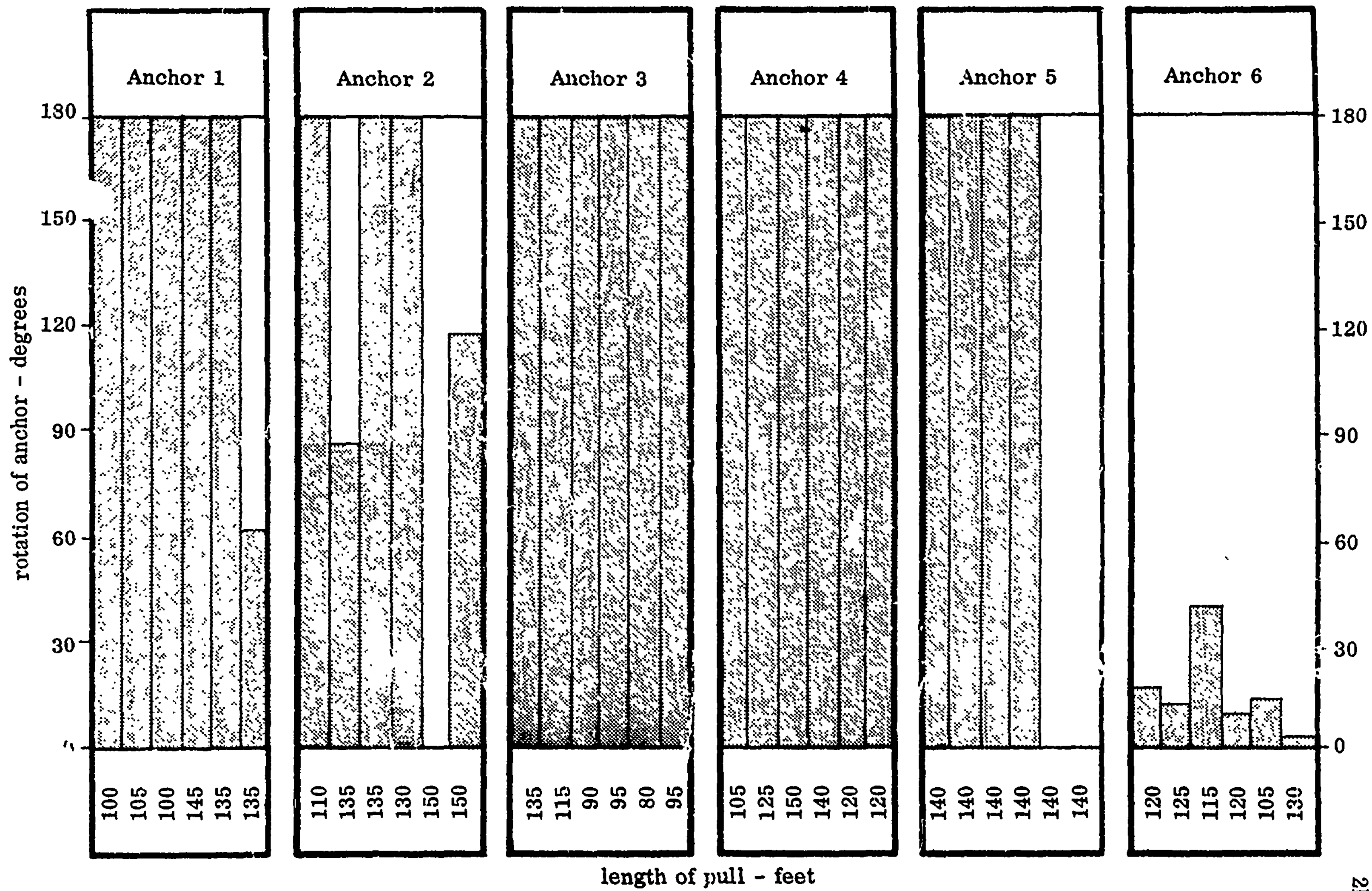


Figure 17. Rotational-stability tests for 30,000-lb stockless anchors.

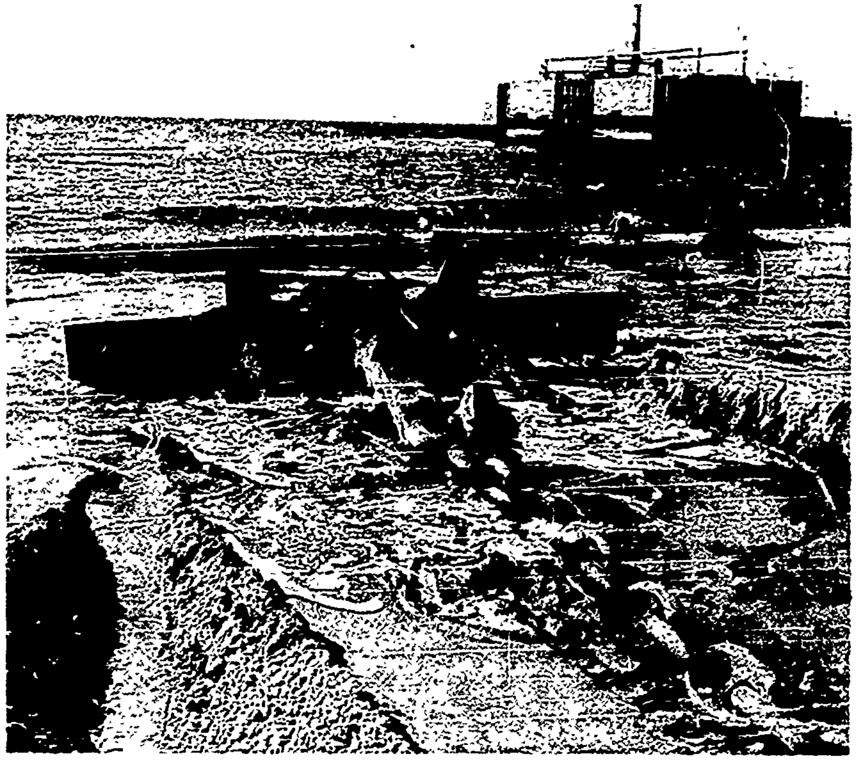


Figure 18. Navy anchor with stabilizers.

stabilizers (shown in Figures 19, 20, 21, and 22) present the effect of the stabilizers on the holding-power of the anchors. The effect of adding stabilizers was to increase the holding-power an average of 10 percent.

A limited number of stockless anchors of various other weights were available in base stock, and tests on these individual anchors were included for comparative purposes.

It was observed during the initial tests on the stockless anchors that, in numerous instances, the flukes did not penetrate the sand sufficiently to bury the anchor. This failure was not caused by insufficient weight of the anchor, as it was observed in the 20,000- and 30,000-lb anchors, as well as the lighter anchors. It was apparent that the line of pull was not being directed through the longitudinal center line of the flukes at such an angle as would permit the anchor to seat itself into the soil, but rather it was allowing the anchor to ride on the tips of the flukes and the end of the shank. A study was made to determine the most efficient "fluke-angle" for anchors operating in a sand bottom.

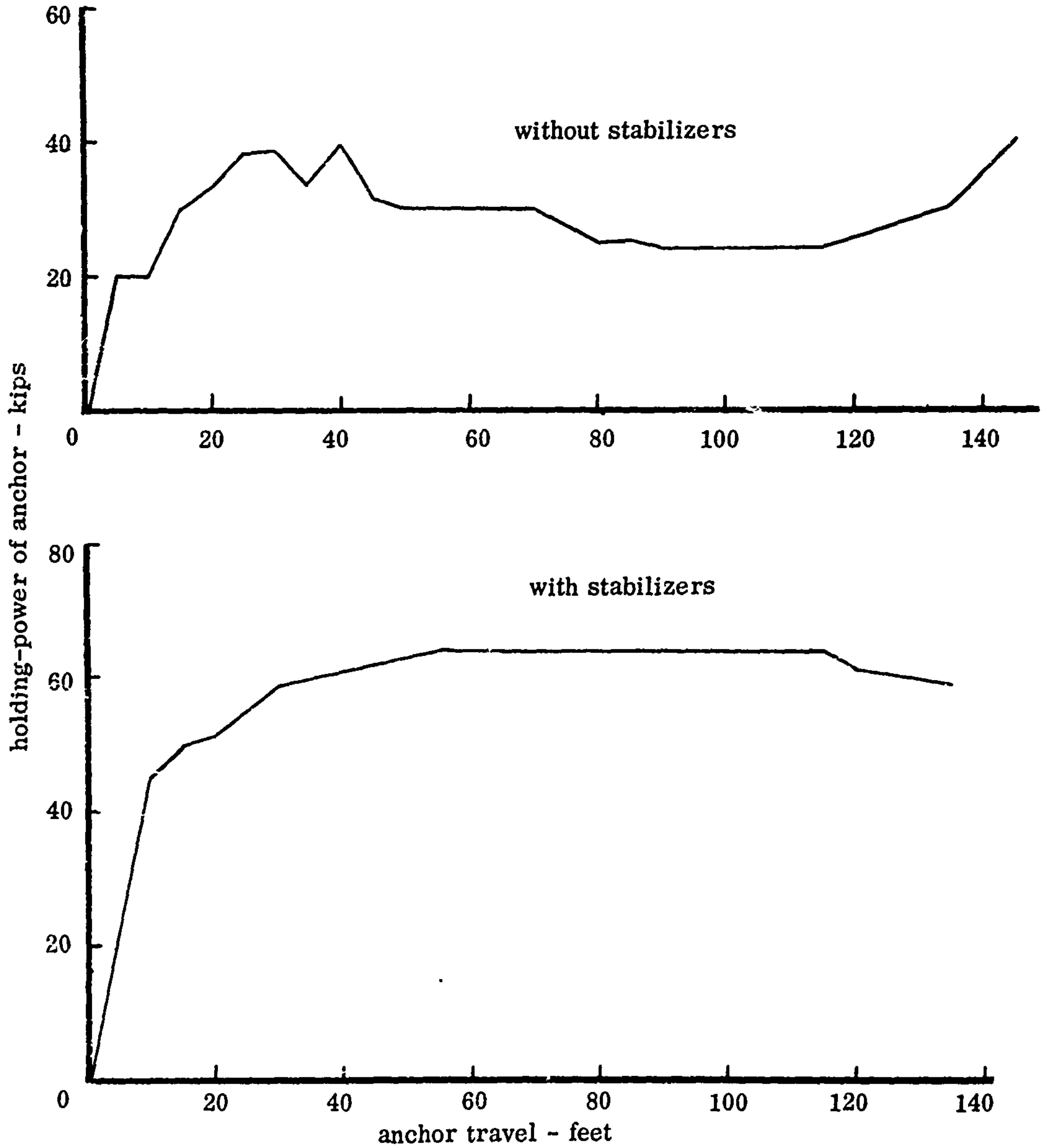


Figure 19. Performance of 6000-lb Navy anchor with and without stabilizers.

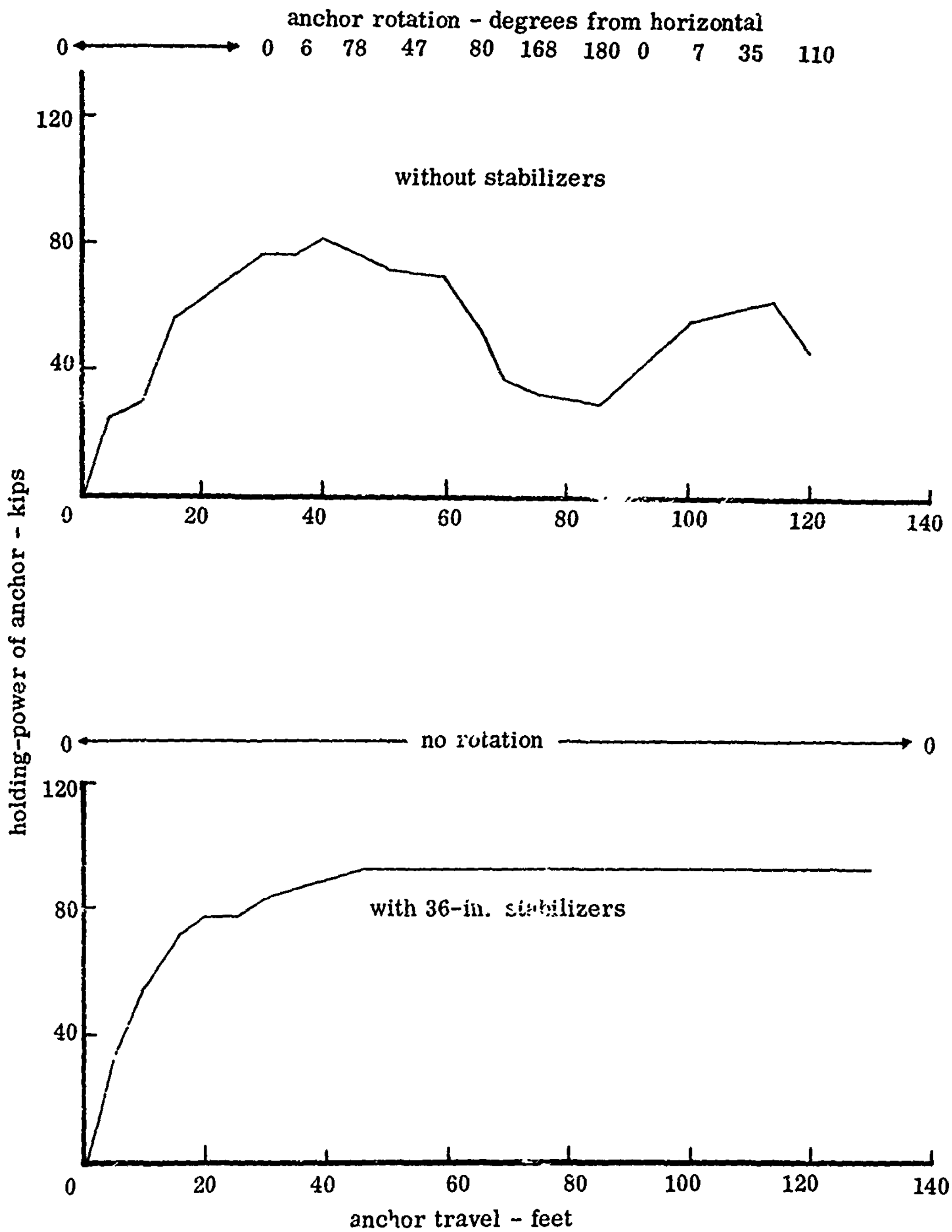


Figure 20. Performance of 10,000-lb Navy anchor with and without stabilizers.

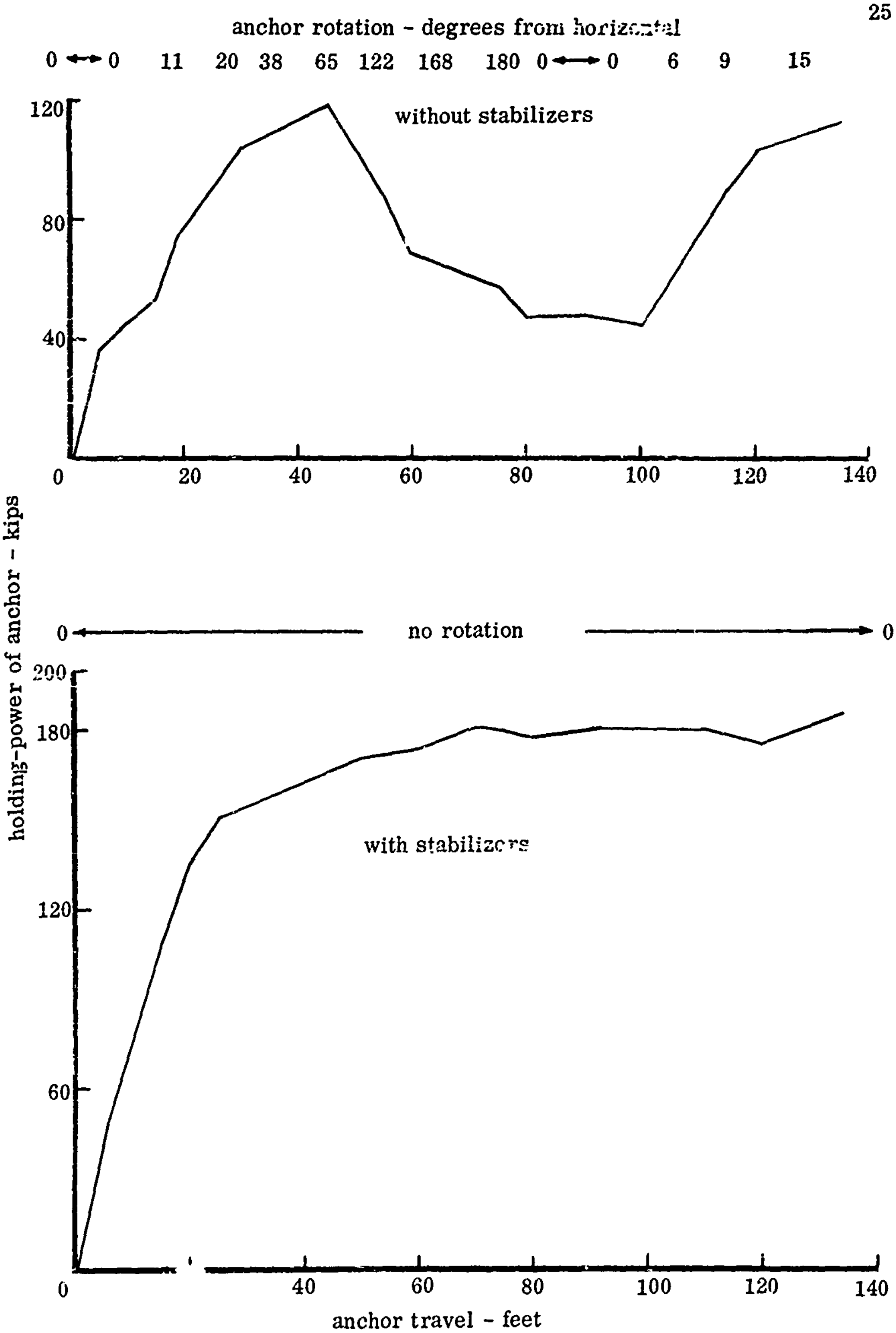


Figure 21. Performance of 18,000-lb Navy anchor with and without stabilizers.

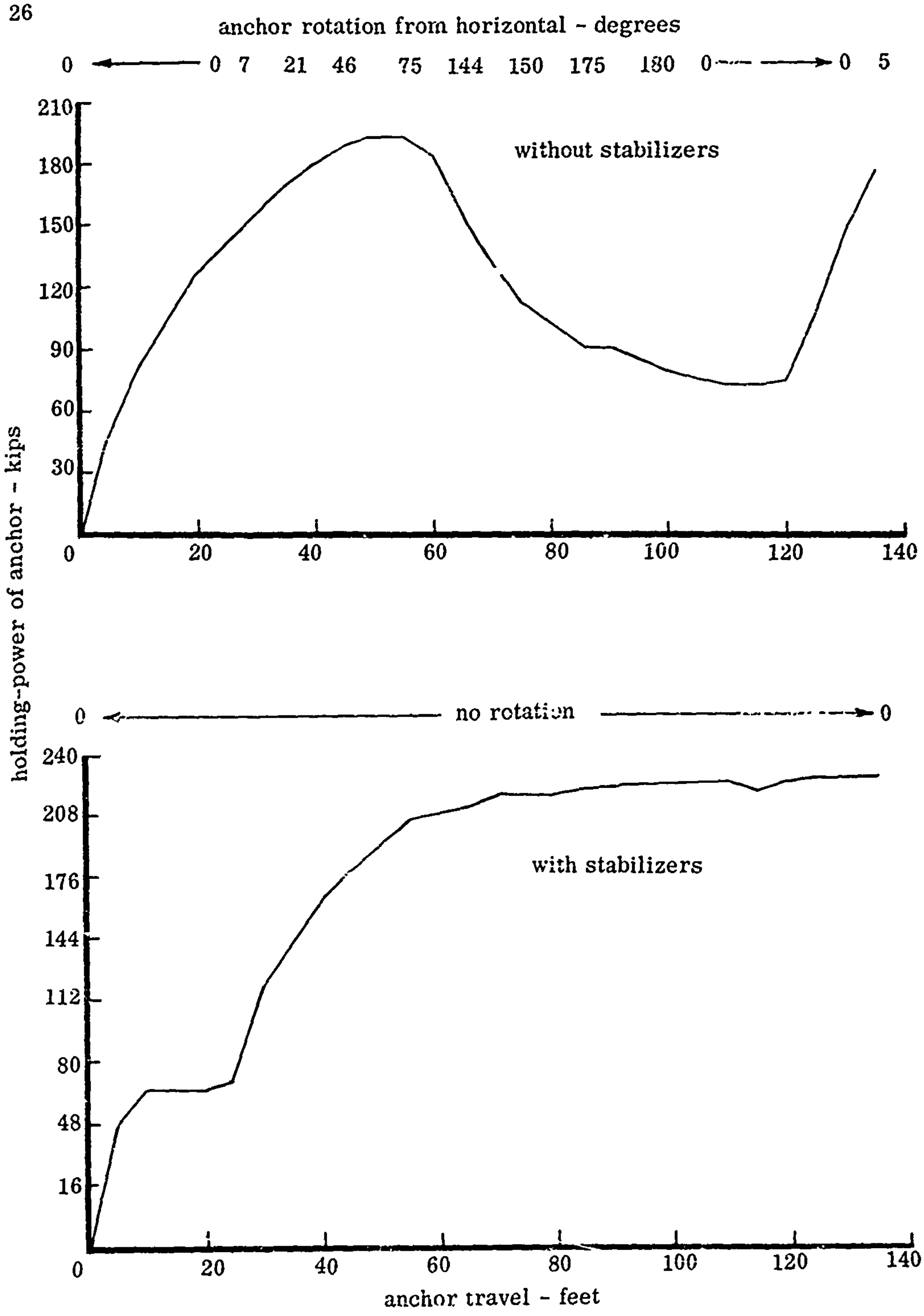


Figure 22. Perfor: ice of 30,000-lb Navy anchor with and without stabilizers.

"FLUKE-ANGLE" TESTS

"Fluke-angle", as used in this report, is the angle subtended between the center line of the shank and the flukes when the flukes are rotated to the extreme open position.

The anchors used in these tests were the 6000-, 10,000-, and 18,000-lb Navy stockless anchors of the Dunn and standard types, and two Danforth anchors weighing 3380 and 10,000 pounds. Original "fluke-angle" measurements were 45 degrees for the 6000- and 10,000-lb anchors, 49 degrees for the 18,000-lb anchor, and 34 and 35 degrees for the 3380- and 10,000-lb Danforth anchors, respectively. When testing, the original fluke opening of each anchor was reduced in decrements of 5 degrees to a minimum angle of approximately 25 degrees. Six test pulls were made at each angle setting.

The critical "fluke-angle", as determined in these tests, was based upon the minimum distance required for the anchor to seat itself into the sand and the maximum holding-power developed after the anchor was embedded. Each test pull began with the anchor laid flat on the sand. Initial tests on the 18,000-lb Navy stockless anchor showed that the anchor would not bury itself into the sand at the original "fluke-angle" of 49 degrees. This anchor (shown in Figure 23) was dragged a distance of 150 ft and remained in an upright position. The average maximum holding-power developed at this time was approximately one-half of the normally anticipated holding-power for an anchor of this weight. The "fluke-angle" was reduced by welding a steel wedge between the crown and the shank of the anchor (shown in Figure 24).

Table II gives the average maximum holding-power of the anchors at each "fluke-angle" setting. A graph of the test results for the 18,000-lb Navy stockless anchor is shown in Figure 25. The curves shown in this graph are the average of the six tests made at each "fluke-angle" setting.

A "fluke-angle" of 35 degrees gave the best results in sand for all of the anchors in this test. This optimum angle has a substantial effect, an increase of 24 percent, on the holding-power over the original "fluke-angle".

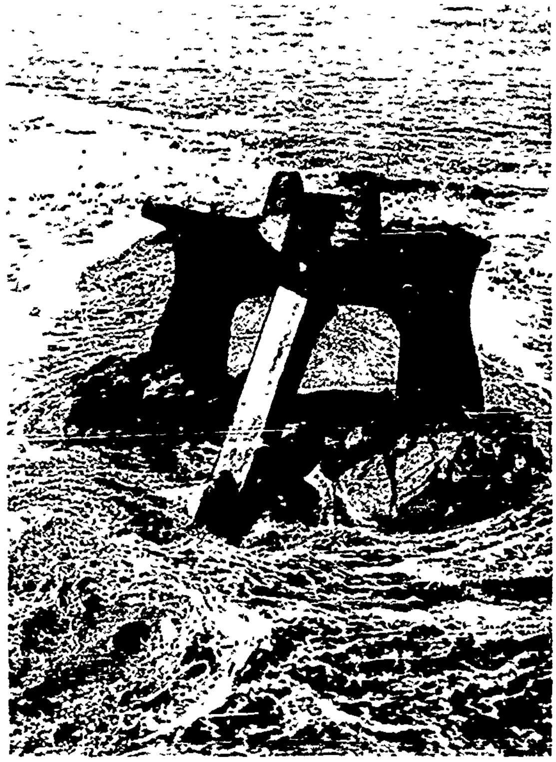


Figure 23. 18,000-lb Navy stockless anchor after diving test.

Figure 2 18,000-lb Navy stockless anchor with 4-in. thick wedge installed.

TABLE II. "Fluke-angle" Test Data — Holding-Power on Beach in Pounds.

"Fluke-Angle"	NSA 6000 lb	NSA 10,000 lb	NSA 18,000 lb	Danforth 3380 lb	Danforth 10,000 lb
49	- -	- -	72,000	- -	- -
45	60,000	95,000	110,000	- -	- -
40	65,000	130,000	155,000	- -	- -
35*	72,000	100,000	210,000	103,000	138,000
30	68,000	92,000	195,000	100,000	135,000
25	67,000	75,000	191,000	95,000	128,000

*Critical "fluke-angle" for anchors operating in sand bottom.

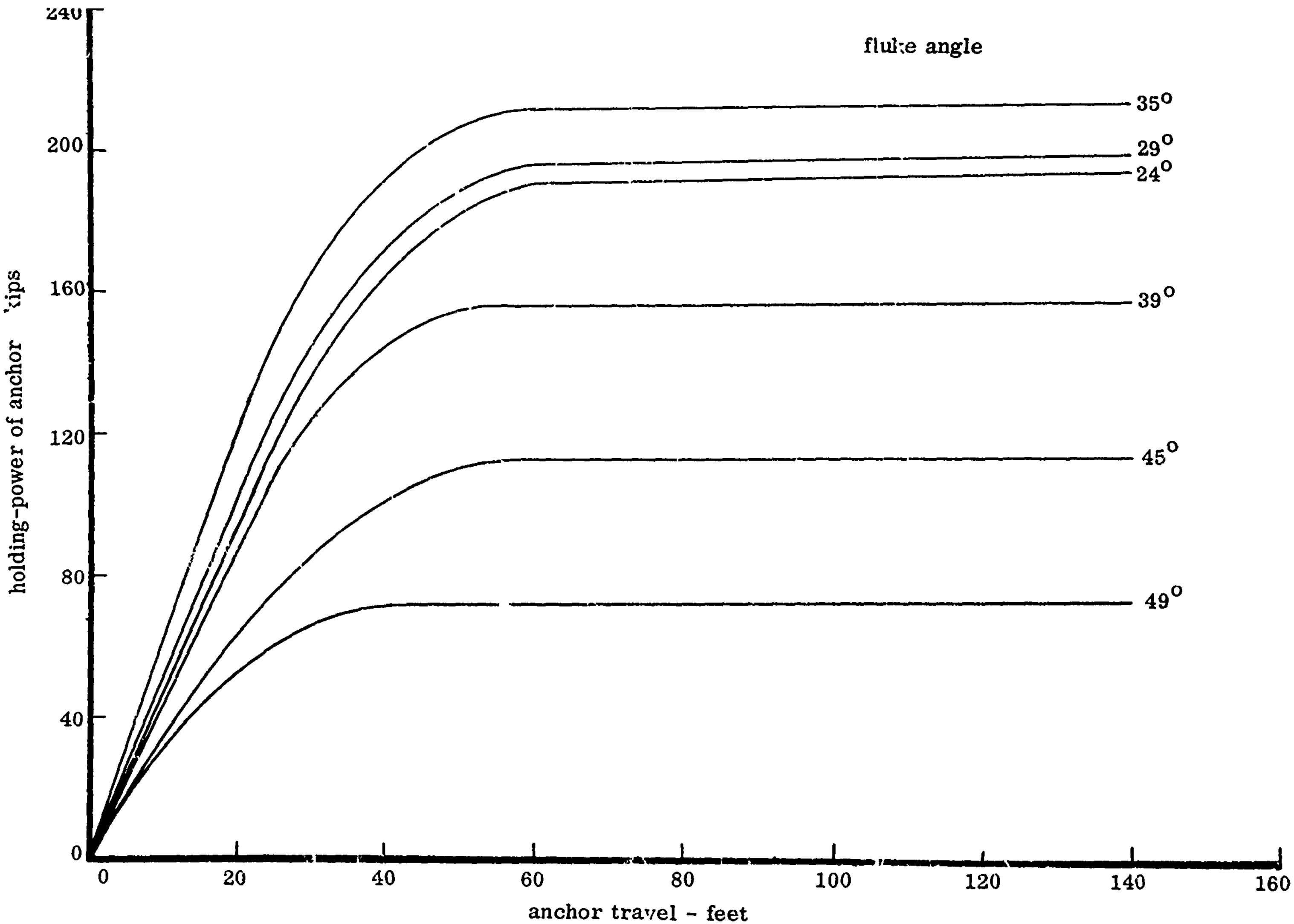


Figure 25. Test results for "fluke-angle" tests on 18,000-lb Navy anchor with stabilizers.

NAVY STOCKLESS ANCHOR WITH SOLID FLUKE

Previously conducted model tests had indicated that the anchor flukes, being relatively close together, act as a solid barrier, filling the space between them when pulled through the ground.

In order to compare the holding-power of a solid-fluke anchor with that of a split-fluke anchor, the 7000-lb Navy anchor, previously tested, was transformed into a solid-fluke anchor by welding a 5/8-in. thick steel plate between the flukes (shown in Figure 26). Six test pulls were made with this stabilized anchor.

With the plate filling the space between the flukes, it was necessary to reduce the "fluke-angle" from the original 45 degrees to 33 degrees in order to force the anchor to bite into the sand. The reduced "fluke-angle" tended to make the anchor more unstable, and the length of the stabilizers had to be increased from 24 in. to 41 in. to counteract the increased rotational torque.

The average holding-power of the anchor was increased from 72,000 lb to 80,000 lb because of the increase in the area of the stabilizer. However, no large increase in holding-power was noted as a result of this larger area of plate between the flukes.

ADMIRALTY ANCHOR

A 5000-lb Admiralty, or old-fashioned-type, anchor was tested for comparative purposes. This type of anchor, because of the construction of its flukes and the position of the stabilizers (shown in Figure 27), digs into the bottom and develops its maximum holding-power in a short distance. Although the fluke-area is small, the arms are long, allowing the fluke to penetrate to a greater depth than a stockless anchor (shown in Figure 28).

Six test pulls were made on this anchor, and the average holding-power obtained was 32.7 kips. Complete data are given in Table I. A graph of one of the six test pulls is shown in Figure 29.

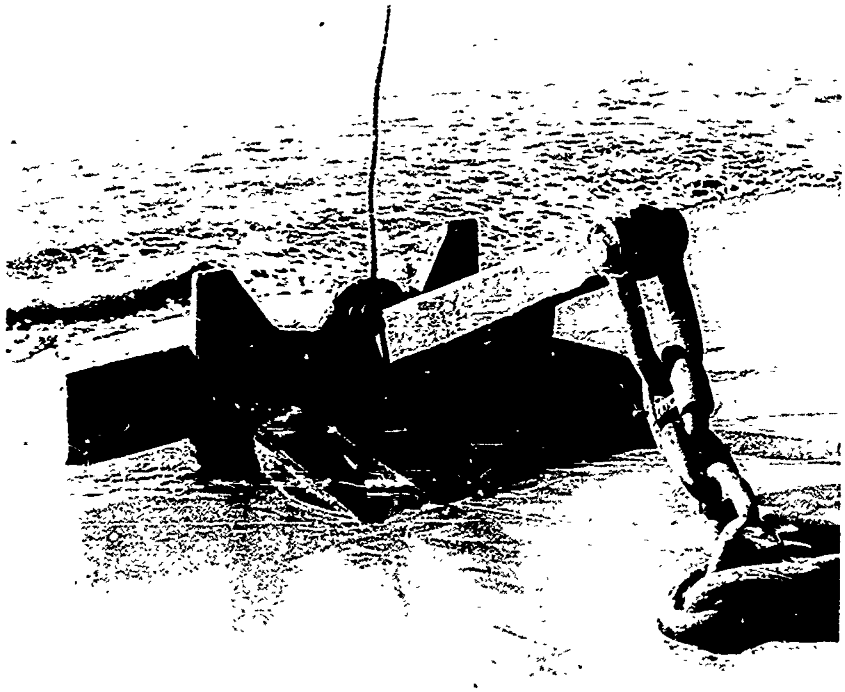


Figure 26. 7000-lb Navy anchor with solid fluke.

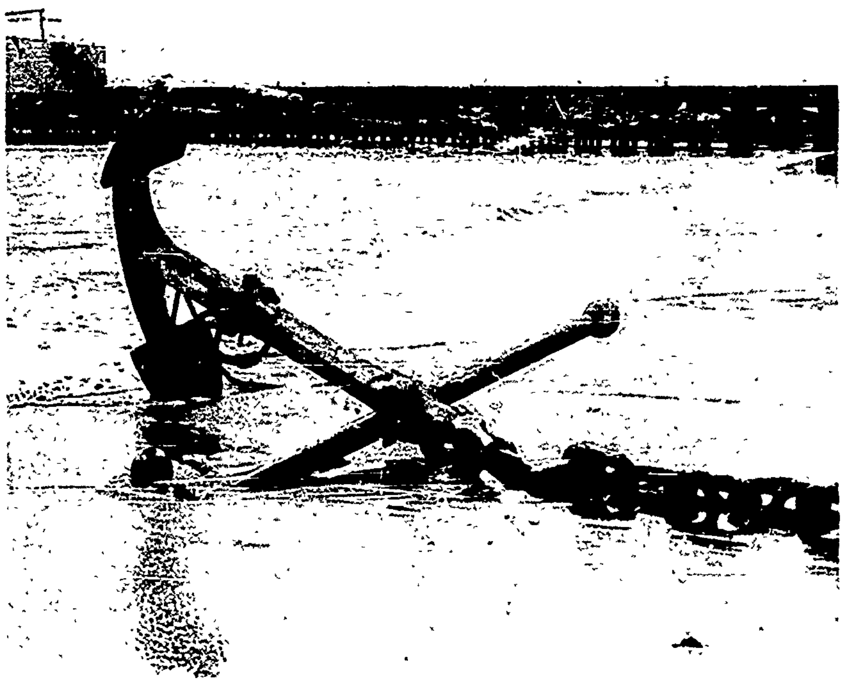


Figure 27. 5000-lb Admiralty anchor.

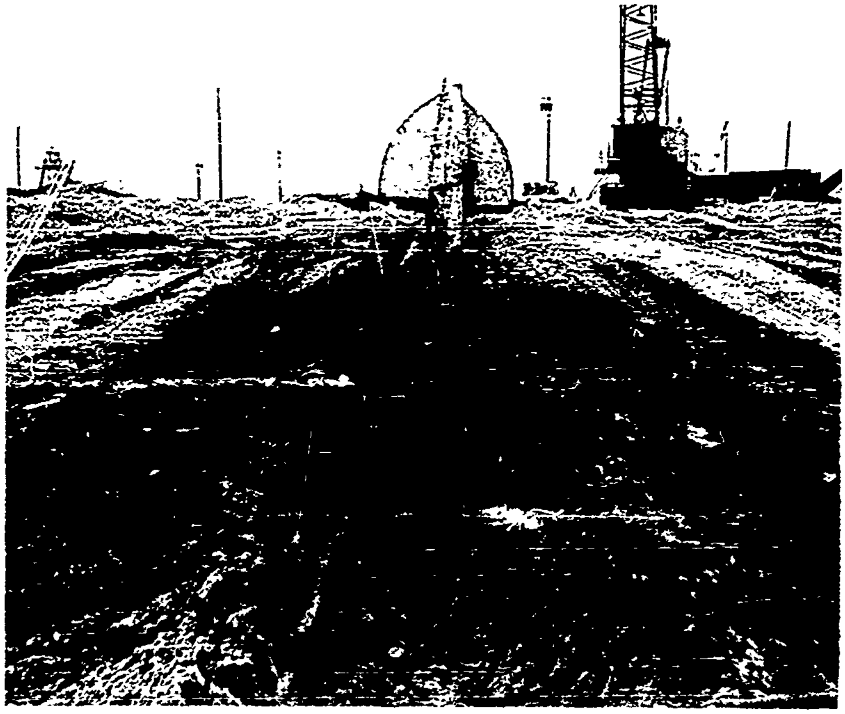


Figure 28. 5000-lb Admiralty anchor during test.

DANFORTH ANCHORS

The Danforth anchors are commercial anchors patented by Mr. R. S. Danforth, of Berkeley, California, and lent to the Laboratory for comparative purposes during these specific tests.

The flukes are fabricated from steel plate rather than by casting, and the anchor is equipped with a steel round-stock stabilizer projecting from the heel of each fluke. This type of anchor does not have the large, round crown found on the Navy stockless anchor; therefore, it will penetrate much deeper into a sand bottom and, because of the greater depth of penetration, will develop a greater holding-power than will stockless anchors of similar weight.

The seven Danforth anchors tested weighed 80, 85, 2510, 2770, 3380, 10,000, and 12,000 pounds. These anchors are shown in Figures 30, 31, 32, 33, 34, 35, and 36, respectively. The 2510-lb

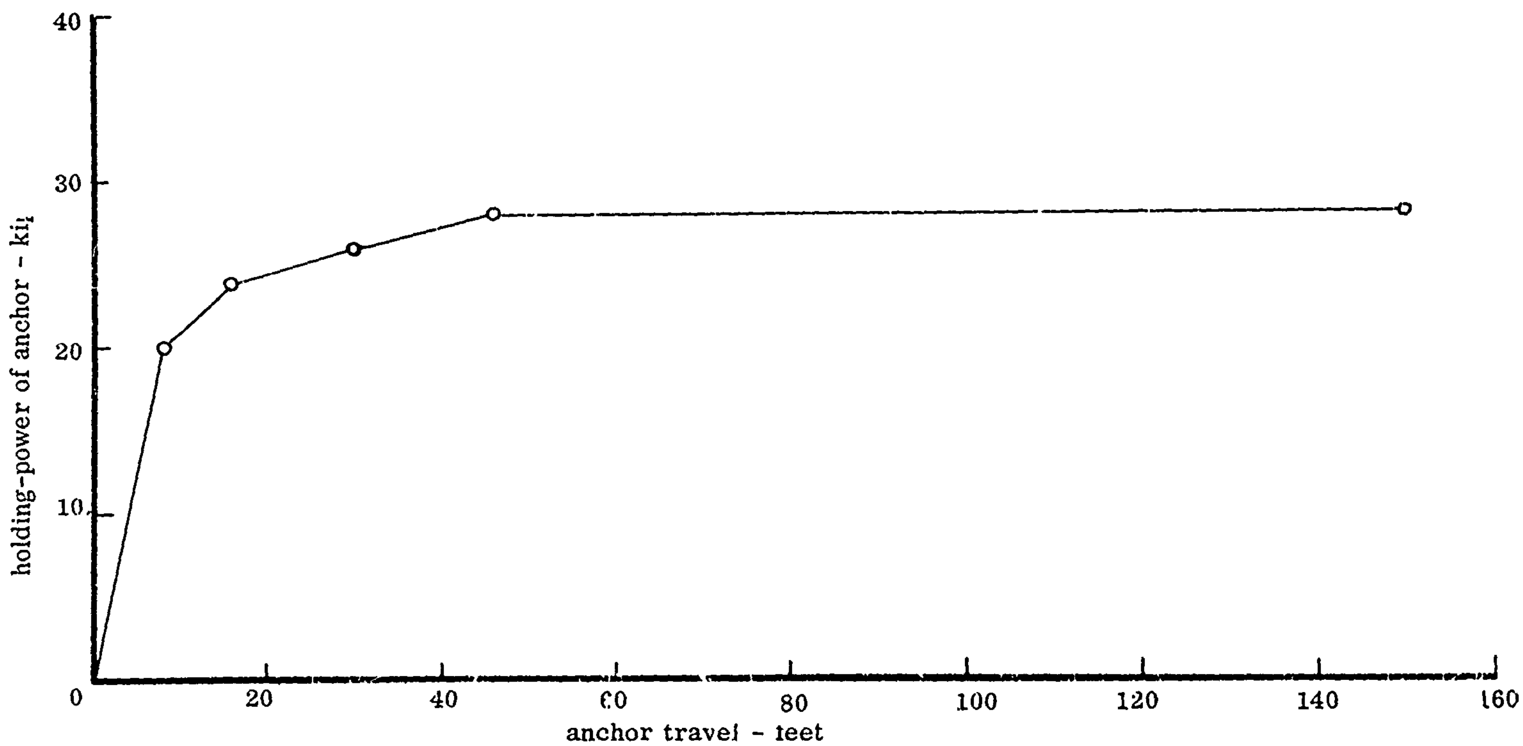


Figure 29. Performance of 5000-lb Admiralty anchor on one test pull.

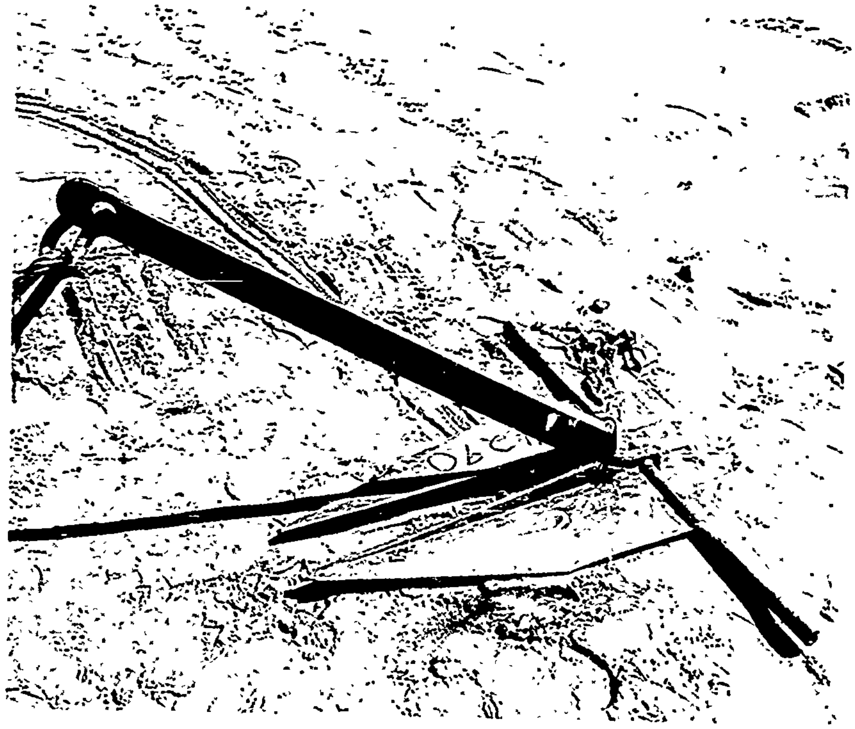


Figure 30. 80-lb Danforth anchor.

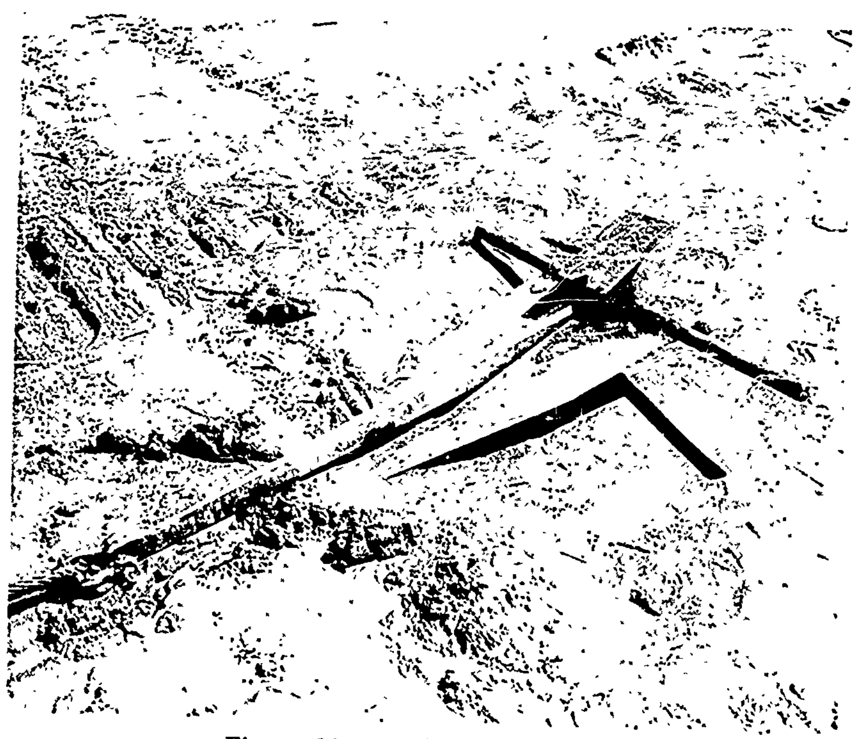


Figure 31. 85-lb Danforth anchor.

Figure 32. 2510-lb Danforth anchor.

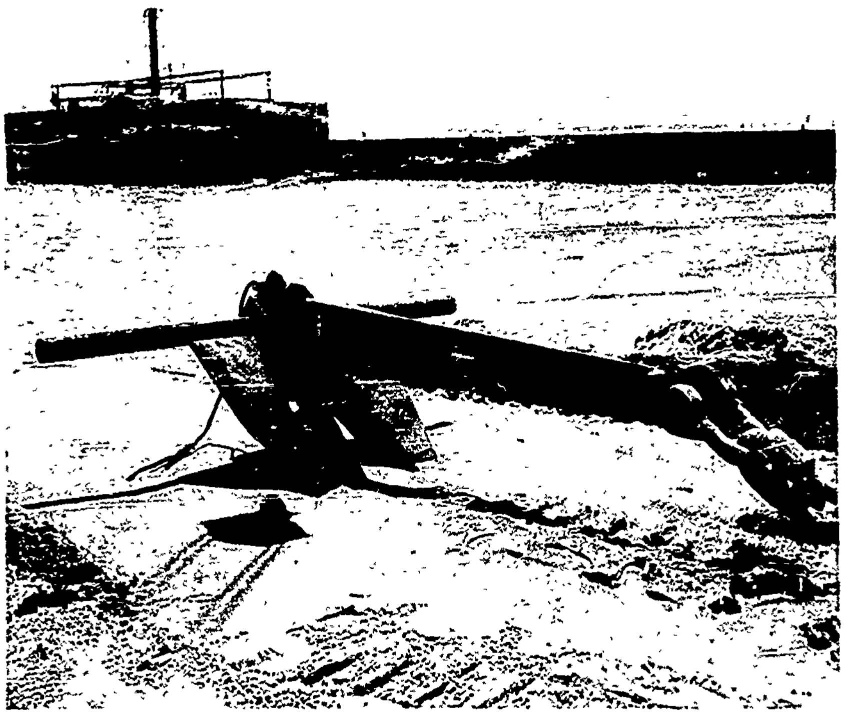


Figure 33. 2770-lb Danforth anchor.

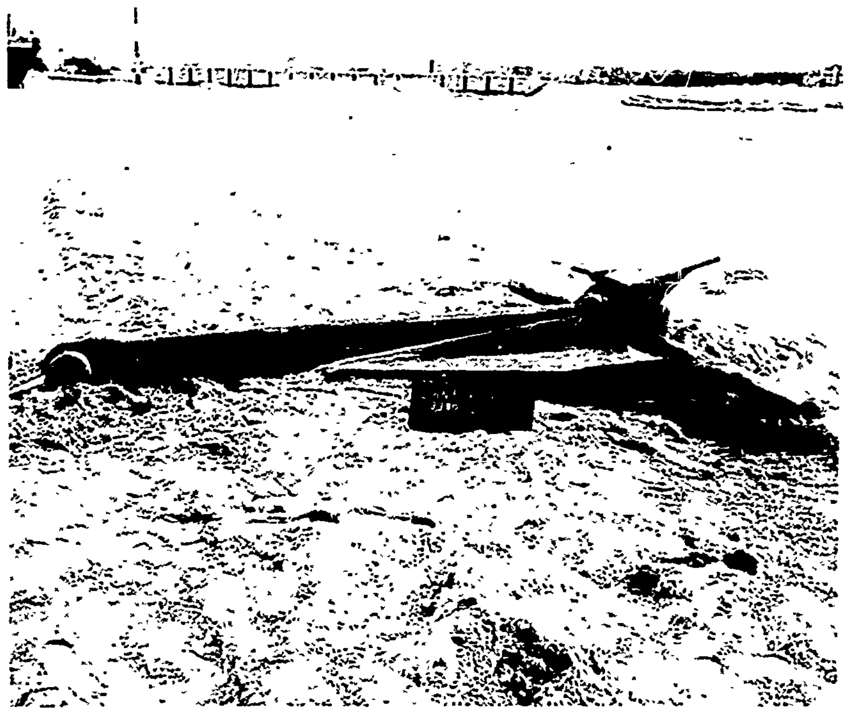


Figure 34. 3380-lb Danforth anchor.

Figure 35. 10,000-lb Danforth anchor.

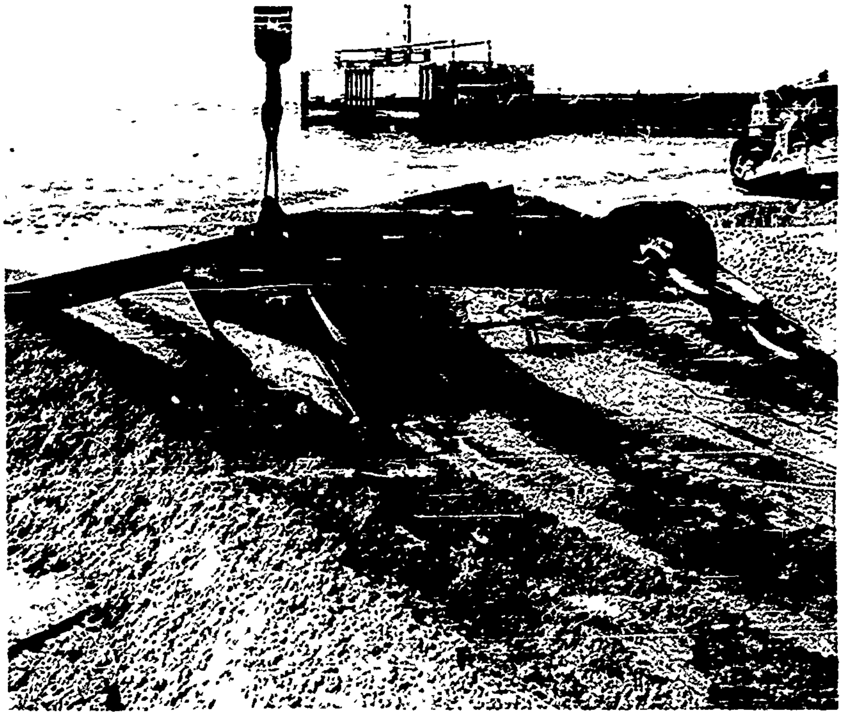


Figure 36. 12,000-lb Danforth anchor.

Figure 37. Two 80-lb Danforth anchors joined in parallel.

anchor is similar to the 7500-lb Navy concrete-steel anchor in that it has but one solid fluke and the shank is fixed at a predetermined angle to the fluke.

Each of the anchors was pulled six times to determine its holding-power. Two of the 80-lb anchors were joined in parallel (shown in Figure 37), and pulled six times.

Table I lists the holding-power of the anchors, size of the stabilizers, and the "fluke-angles." Graphs of one test pull of the 2510, 2770, 3380, 10,000, and 12,000-lb anchors, respectively, are shown in Figures 38, 39, 40, 41, and 42.

CONCRETE ANCHORS

The concrete anchors built in accordance with BUDOCKS drawing no. 461,584[7] for test purposes, consisted of one 10,580-lb wedge-type (shown in Figure 43), one 10,500-lb mushroom-type (shown in Figure 44), and four 2470-lb mushroom-type (shown in Figure 45). E-1 specifications for 3000-psi ultimate strength concrete, as given in BUDOCKS publication 13YC, "Specifications for Concrete Construction USN," were used in constructing the anchors.

The four 2470-lb mushroom anchors were to be pulled in tandem; therefore, a 1-1/2 in. cast-steel chain was embedded longitudinally through the anchors; and the chain was prestressed prior to pouring the concrete and for 7 days after pouring (shown in Figure 46). Concrete compression-test specimens, taken at the time of pouring, had a maximum strength of 3061 psi after 28 days.

Tests were performed as prescribed in BUDOCKS instructions, "Suggested Testing Procedure for Determining Safe Holding-Power of Concrete Anchors, Wedge- and Mushroom- Type," contained in Appendix C. The 10,580-lb wedge and 10,500-lb mushroom anchors were each pulled six times, and the average maximum holding-powers were 44.6 kips and 30.3 kips, respectively. The four 2470-lb anchors were connected in tandem, with 30 ft of 1-1/2 in. anchor chain between anchors, and tested. The average maximum holding-power in the sand bottom was 3.8 kips.

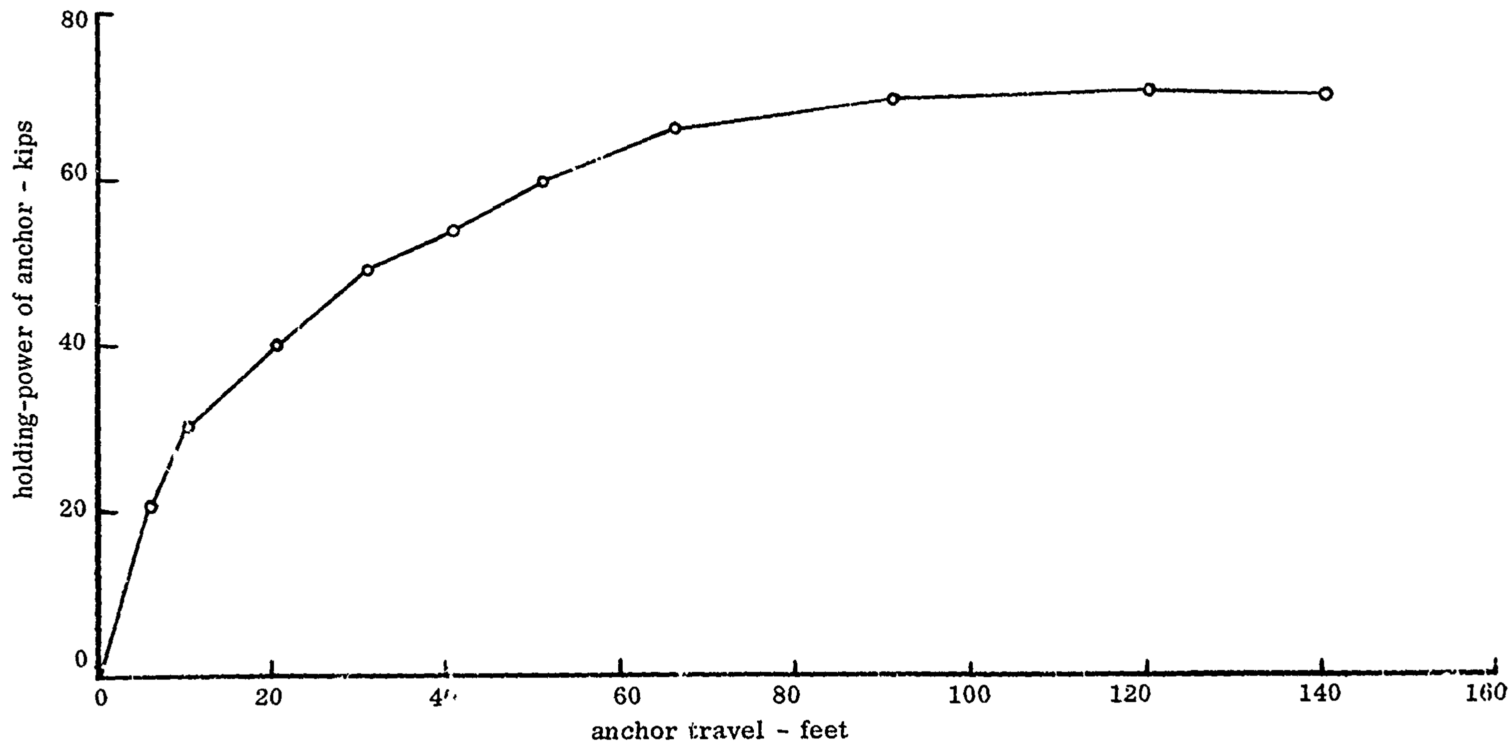


Figure 38. Performance of 2510-lb Danforth anchor on one test pull.

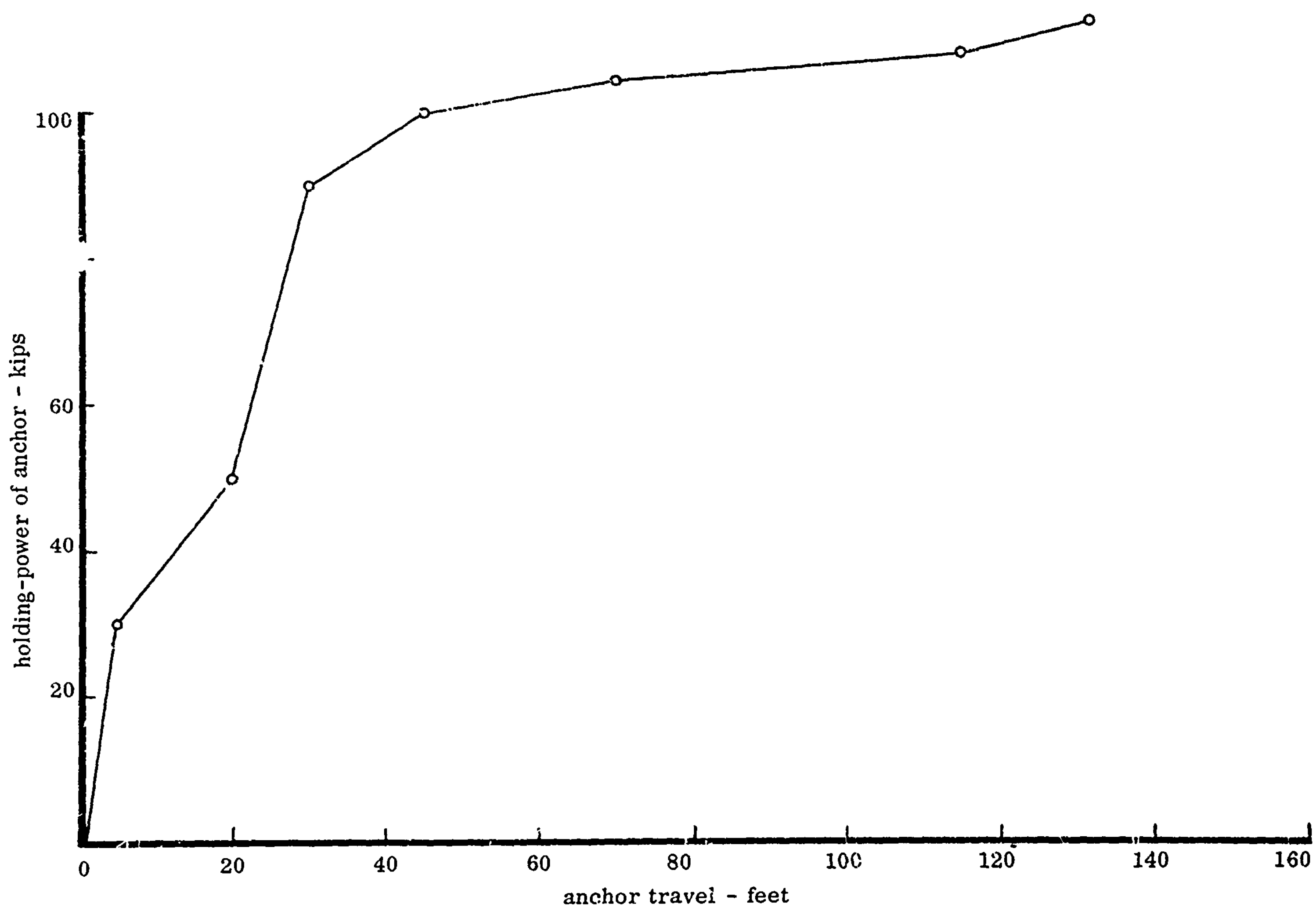


Figure 39. Performance of 2770-lb Danforth anchor on one test pull.

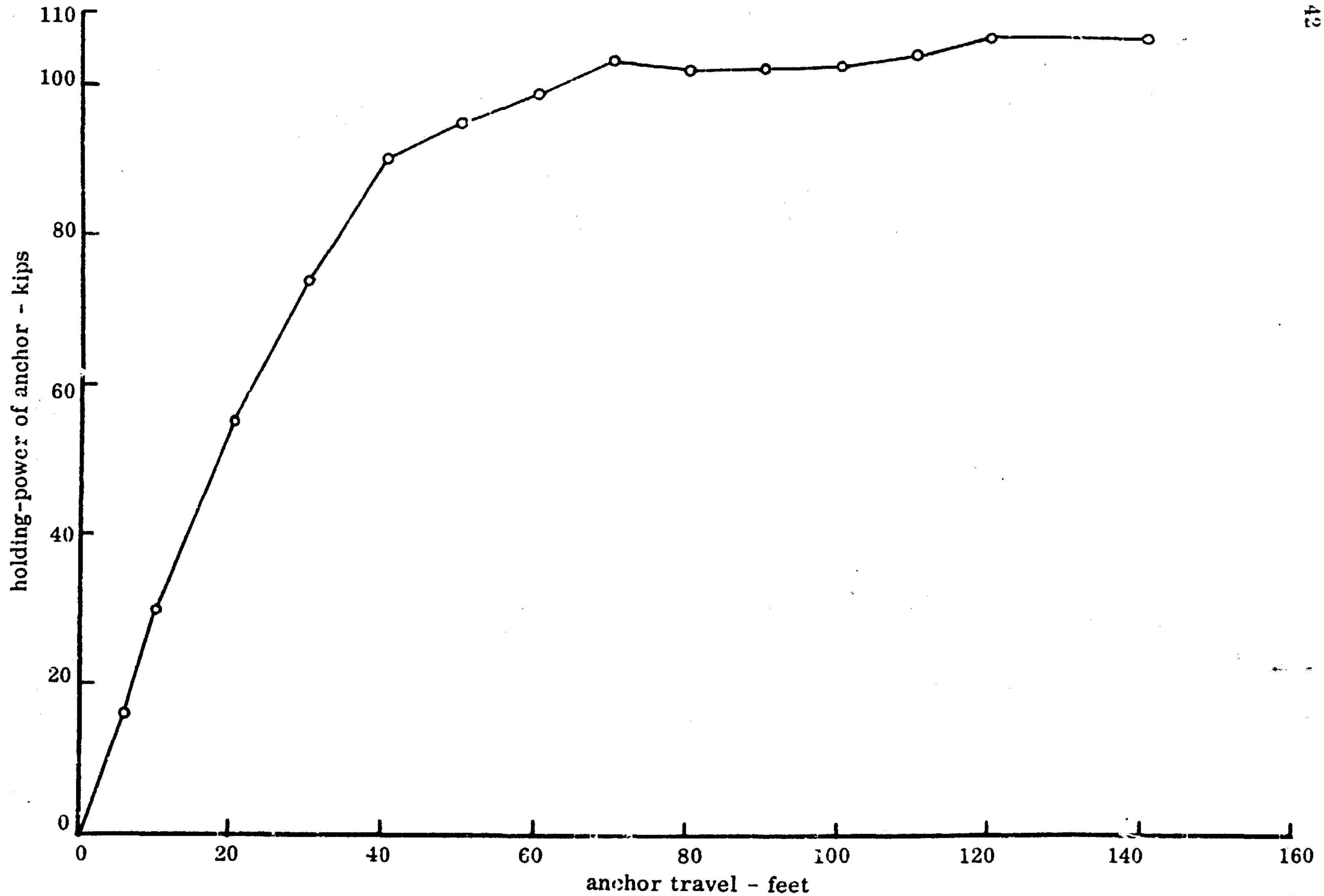


Figure 40. Performance of 3380-lb Danforth anchor on one test pull.

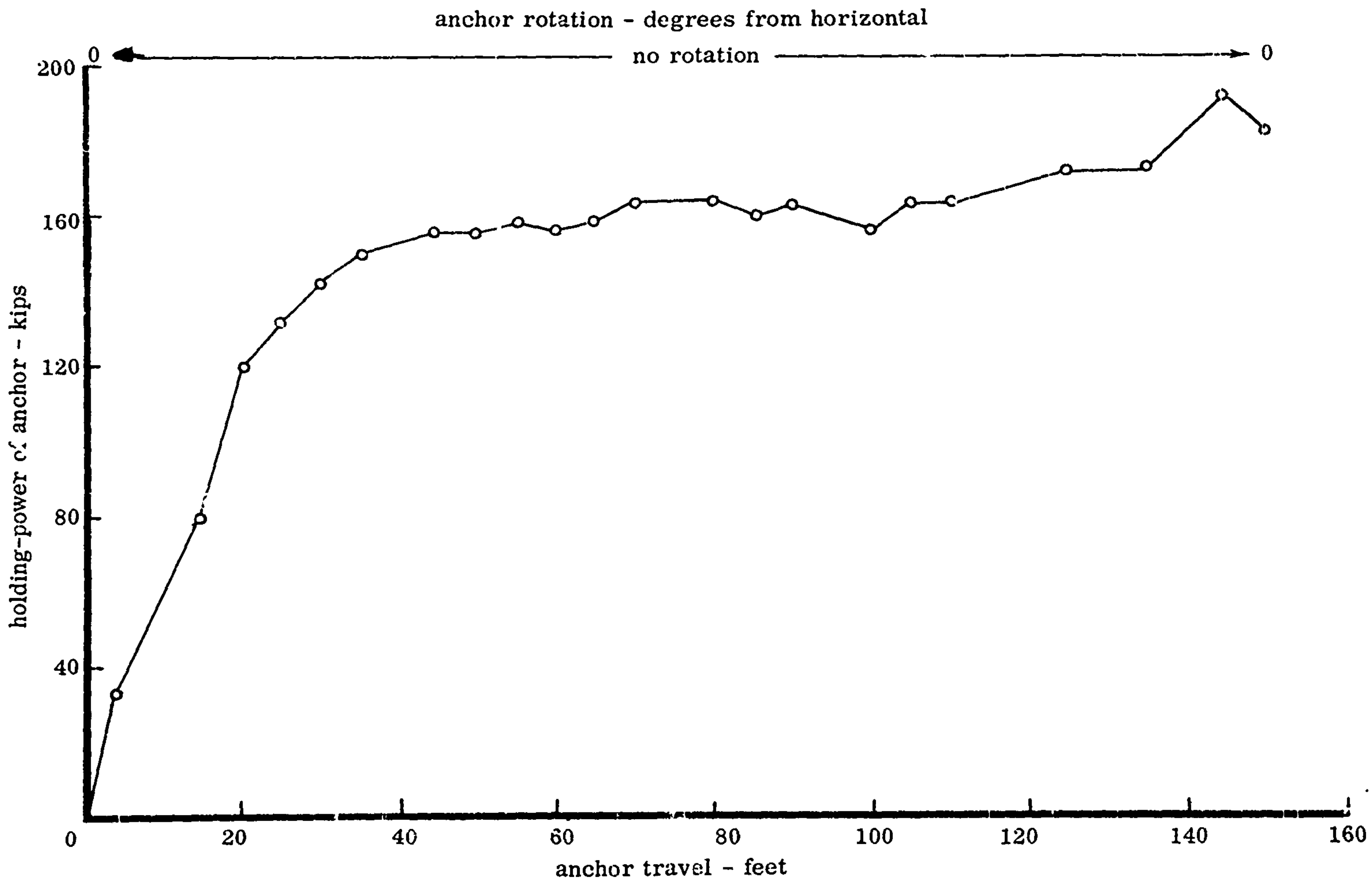


Figure 41. Performance of 10,000-lb Danforth anchor on one test pull.

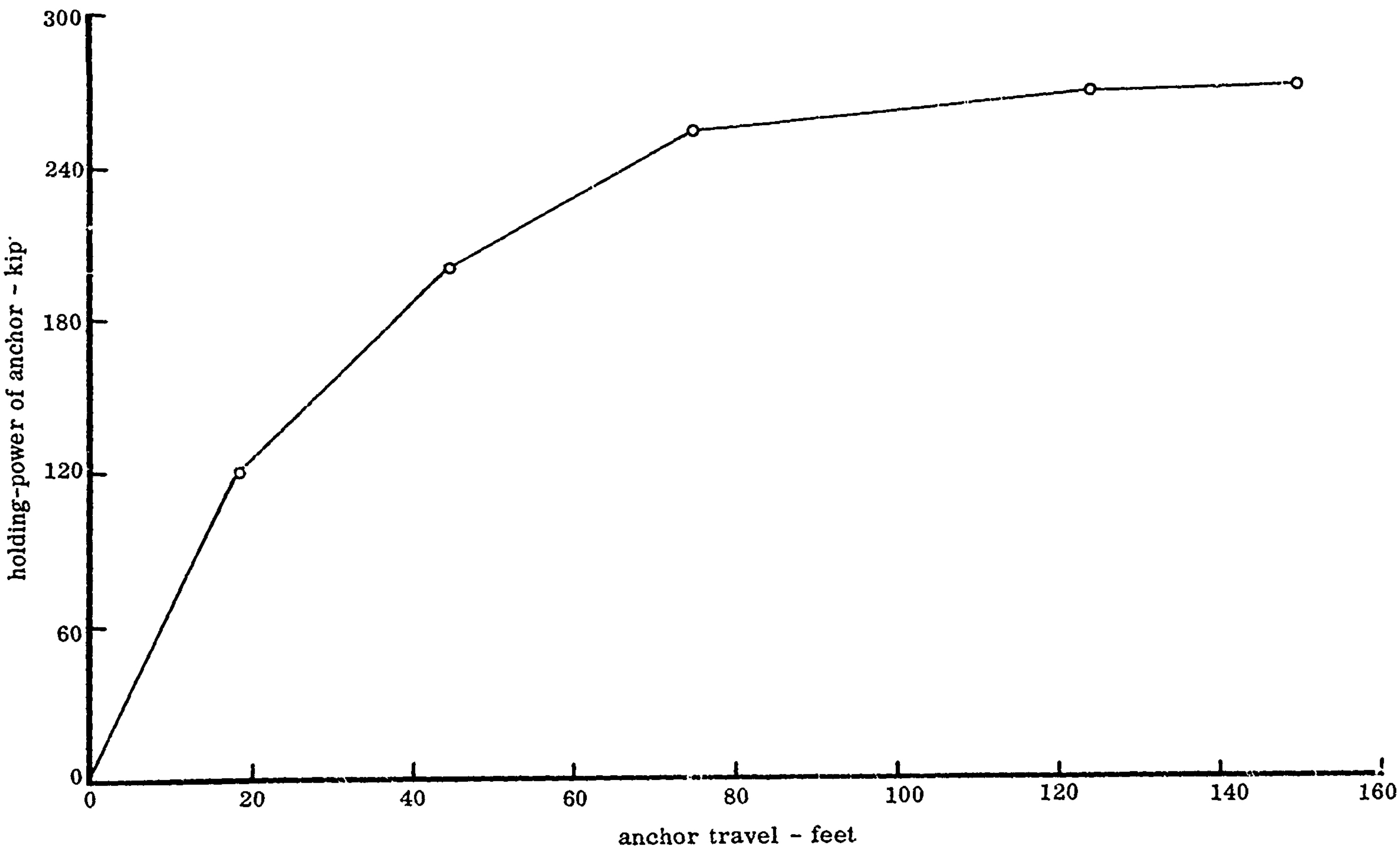
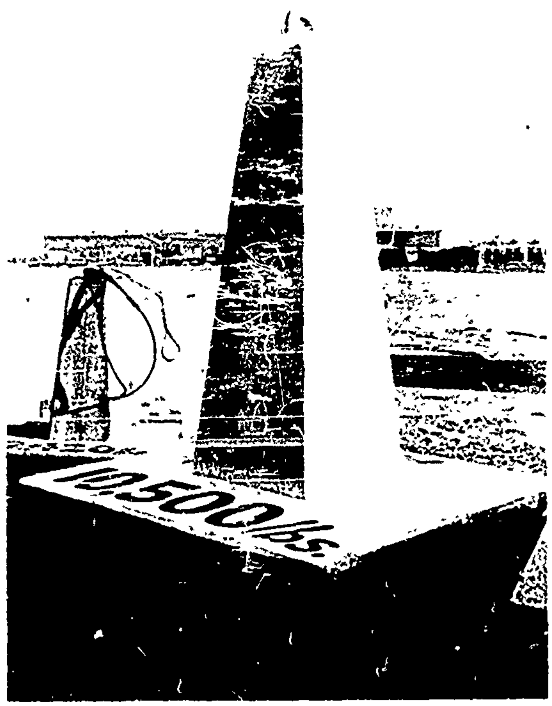


Figure 42. Performance of 12,000-lb Danforth anchor on one test pull.

Figure 43. 10,580-lb wedge-type concrete anchor.



Fi e 44. 10,500-lb mushroom-type concrete anchor.

Figure 45. 2470-lb mushroom-type concrete anchors.

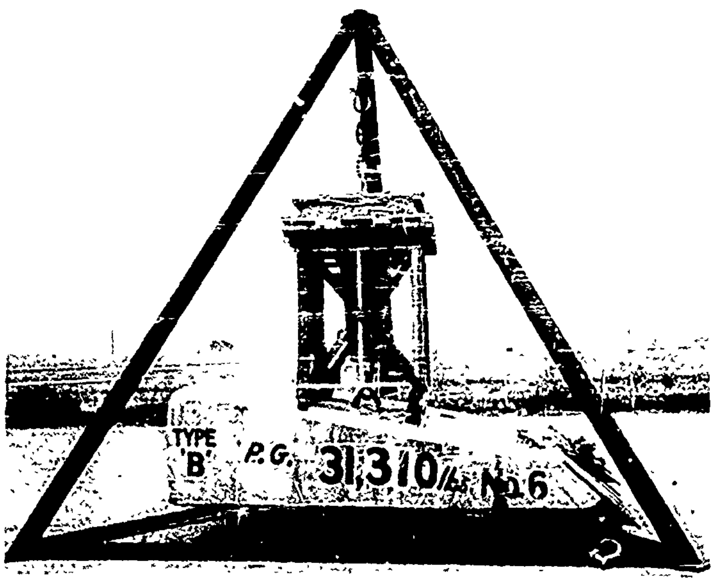


Figure 46. Prestressing longitudinal chain in 2470-lb mushroom-type concrete anchor.

HOLDING-POWER TESTS UNDER WATER

The stabilized anchors were tested under 20 ft of water in a sand bottom to determine their holding-powers with chain angles of 0, 6, and 12 degrees.

The testing apparatus consisted of two 5 x 12 pontoon barges, used to carry the test equipment, and a 5 x 12 pontoon warping tug, used to set the anchors. The test equipment was composed of a 600,000-lb capacity dynamometer to measure the holding-power of the anchors and a model BU-140 Skagit winch with a six-part line for dragging the anchors. The winch was spooled with 2500-ft of 1-3/8 in. diameter wire rope, and the wire rope was reeved through sheaves mounted on the two barges to form the six-part line (shown in Figure 47).

Figure 47. Test apparatus for conducting the anchor tests under water. Anchor being tested is located by buoy at far end of barge.

The warping-tug winch was used to pull the test anchor loose from the sand after a test pull and to reset it for the next pull.

T .orce required to break the test anchor loose from the sand was measured by means of a Martin-Decker strain gage mounted on the warping-tug winch line.

TEST RESULTS

Each of the stabilized anchors was pulled at chain angles of 0, 6, and 12 degrees. Six tests were conducted with each anchor at each chain angle. Results of these tests are given in Table III. The holding-power, break-out force, and chain angles are shown for each anchor.

Additional comparative tests were made with four Navy stockless anchors without stabilizers and three Danforth anchors. Values for these tests are also given in Table III.

A comparison of the beach test results, Table I, and water test results, Table IV, shows a reduction in holding-power for the 10,000-lb Navy stockless with stabilizers from 90,900 lb to 53,800 lb or 41 percent, when in water. The average reduction for Navy anchors is 37.7 percent, and for Danforth anchors is 34.0 percent.

Changing the chain angle from zero to 6 and 12 degrees, on the Navy stockless anchors, reduced the holding-power by an average of 15.1 and 38.9 percent, respectively.

The 10,530-lb wedge and the 10,500-lb mushroom-concrete anchors were each pulled six times at chain angles of zero and 6 degrees. The four 2470-lb mushroom anchors were pulled in tandem, close-coupled and also with 30-ft intervals between anchors. The results of these tests are contained in Table IV.

SOIL SAMPLES

Samples of the soil were taken in the path of the test pulls down to a depth of 12 feet. The sampling equipment consisted of a Porter Sampler guided by a 30-ft lead and driven with a 300-lb drop hammer. The power for lifting the 300-lb hammer was supplied by a two-drum 75-hp Jaeger winch. The leads and winch were mounted on a pontoon barge which could be submerged to rest on the ocean bottom, in order to furnish a stable platform for driving the sampler. A 215-cfm air compressor mounted on the deck was used to raise the barge from its submerged position. The barge was 21-ft square and 24-ft high.

TABLE III. Holding-Power Data of Steel Anchors Tested Under Water.

Type	wt (lb)	"Fluke-angle" degrees	Stabilizers (in.)			Average holding-power (lb)			Chain angle degrees	Break-out force (lb)
						length of drag				
			width	thickness	length	50 ft	100 ft	150 ft		
Standard	5000	33	16	1/2	42	28,200	31,200	30,600	0	11,500
Standard	5000	33	16	1/2	42	25,300	25,500	25,500	6	11,500
Standard	5000	33	16	1/2	42	21,300	23,300	27,600	12	11,500
Dunn	6000	35	16	1/2	42	35,300	50,100	54,000	0	22,966
Dunn	6000	35	16	1/2	42	33,000	35,700	34,000	6	20,633
Dunn	6000	35	16	1/2	42	20,300	22,700	25,300	12	19,366
Dunn	10000	47	19	3/4	36	53,800	64,300	70,300	0	44,600
Dunn	10000	47	19	3/4	36	46,300	49,000	49,000	6	35,300
Dunn	10000	47	19	3/4	36	27,300	32,000	34,000	12	33,300
Dunn	30000	34	23	1	50	133,200	196,400	237,000	0	70,900
Dunn	30000	34	23	1	50	93,700	122,500	135,200	6	77,400
Dunn	30000	34	23	1	50	81,000	98,000	111,600	12	104,100
Danforth	85	37	1-1/8	round	12	13,200	15,300	- -	0	- -
Danforth	80	37	1-1/8	round	12	9,600	12,400	- -	0	- -
Danforth	2510	32	4-1/2	round	51-1/2	35,700	40,000	40,900	0	8,750
Danforth	2510	32	4-1/2	round	51-1/2	40,000	40,300	43,000	6	5,630
Danforth	2510	32	4-1/2	round	51-1/2	26,000	29,900	35,200	12	7,133
Danforth	2770	33-1/2	4-1/2	round	51-1/2	52,500	63,300	65,300	0	14,000
Danforth	2770	33-1/2	4-1/2	round	51-1/2	51,200	70,000	78,000	6	24,560
Danforth	2770	33-1/2	4-1/2	round	51-1/2	49,000	57,000	61,200	12	25,600
Danforth	3380	-	-	-	-	66,000	81,200	81,600	0	17,766
Danforth	3380	-	-	-	-	64,400	86,700	93,200	6	19,200
Danforth	3380	-	-	-	-	59,700	65,300	73,200	12	14,000
Danforth	10000	34	34	5-1/2	62-1/2	106,300	119,000	124,200	0	74,500
Danforth	10000	34	34	5-1/2	62-1/2	72,200	102,200	101,500	6	86,500
Danforth	10000	34	34	5-1/2	62-1/2	64,000	73,000	76,600	12	76,666
Concrete-steel	7500	-	-	-	-	52,500	55,500	57,600	0	27,600
	7500	-	-	-	-	56,500	59,900	59,500	6	26,033
	7500	-	-	-	-	35,900	44,600	42,900	12	26,600

TABLE IV. Holding-Power Data of Concrete Anchors Tested Under Water.

Anchors		Average holding-power in pounds length of drag			Chain angle degrees
type	weight	50 ft	100 ft	150 ft	
Wedge	10,580	25,000	27,300	27,500	0
Wedge	10,580	15,200	18,300	20,000	6
Mushroom	10,500	21,300	23,000	21,600	0
Mushroom	10,500	13,000	14,700	14,800	6
Mushroom*	2,470	18,000	19,800	21,000	0
close coupled	2,470	10,000	11,600	12,500	6
Mushroom*	2,470	17,000	18,600	21,000	0
30 ft apart	2,470	7,500	7,500	7,[illegible]50	6

*Four 2470-lb anchors joined in tandem.

The firmness of the sand bottom adjacent to each anchor breakout test location was determined by means of a pipe-penetration test. For this purpose, the Porter Sampler was capped at the bottom end and driven with the soil-sampling equipment. The fall of the 300-lb hammer was automatically controlled at 24 in. by means of a trip release. The tests were taken down to the depth of anchor-penetration.

DISCUSSION

In a theoretical determination[8] of how the weight of an anchor depends upon its size for a given load factor and maximum permissible stress, it can be shown that:

$$P \propto W$$

$$\frac{P}{W} = \left(\frac{k}{\rho}\right)\left(\frac{P}{L^3}\right)^{1/3}\left(\frac{f}{ND}\right)^{2/3} \qquad (1)$$

where P = anchor holding-power

W = anchor weight

k = non-dimensional coefficient depending upon material distribution in the mean cross-section

ρ = weight per unit volume of anchor material

L = characteristic linear over-all dimension

f/N = maximum permissible stress

D = a factor of linear dimensions depending upon the structural economy of the shape of the anchor.

In equation (1), the factors on the right-hand side and their product on the left-hand side are constant under the given or assumed conditions. As the failing stress f is constant, the load factor varies inversely as the linear scale, thus:

$$N \propto \frac{1}{D} \propto \frac{1}{L}$$

Therefore, in a series of anchors which are geometrically similar in all respects, the larger are relatively weaker than the smaller in proportion to the linear scale.

From the results of the data gathered during these tests, it appears that the validity of the L^3 law, or linear-dimension theory, is reaffirmed. That is, since the holding-power is a function of the volume of bottom material disturbed, the holding-power should dimensionally be a volume or linear dimension cubed. However, as shown in the Leahy and Farrin model studies. it is the moment of the projected fluke-area which is more nearly related to the anchor holding-power. A graph of holding-power versus fluke-area moment is shown in Figure 48. This graph is plotted for Navy anchors with and without stabilizers and for Danforth anchors, and it shows the close relationship of the holding-power to fluke moment of different type anchors.

EFFECT OF SOIL ON HOLDING-POWER

The report[9] states that sand tends to bulk or densify during shear such as occurs when an anchor is being dragged through the soil. Movement or shifting of sand particles under water is resisted by the viscosity of water; therefore, sand under water is not as dense in-place as is sand on the shore. Consequently, larger holding-powers will be obtained during beach tests on an anchor than will be obtained during under-water tests, as can be seen by comparing the holding-powers given in Tables I and III.

The soil samples taken during the water tests were given shearing tests after separation and classification of the sands. The sands at the test site were divided into three groups: fine sand, medium sand, and coarse sand. The graduations for the three types of sands are shown in Figures 49, 50, and 51, respectively. In the shearing tests, the initial and final voids ratios were determined for each individual shearing test. The voids ratio is the volume of voids divided by the volume of solids in a given volume of sand. Thus, in

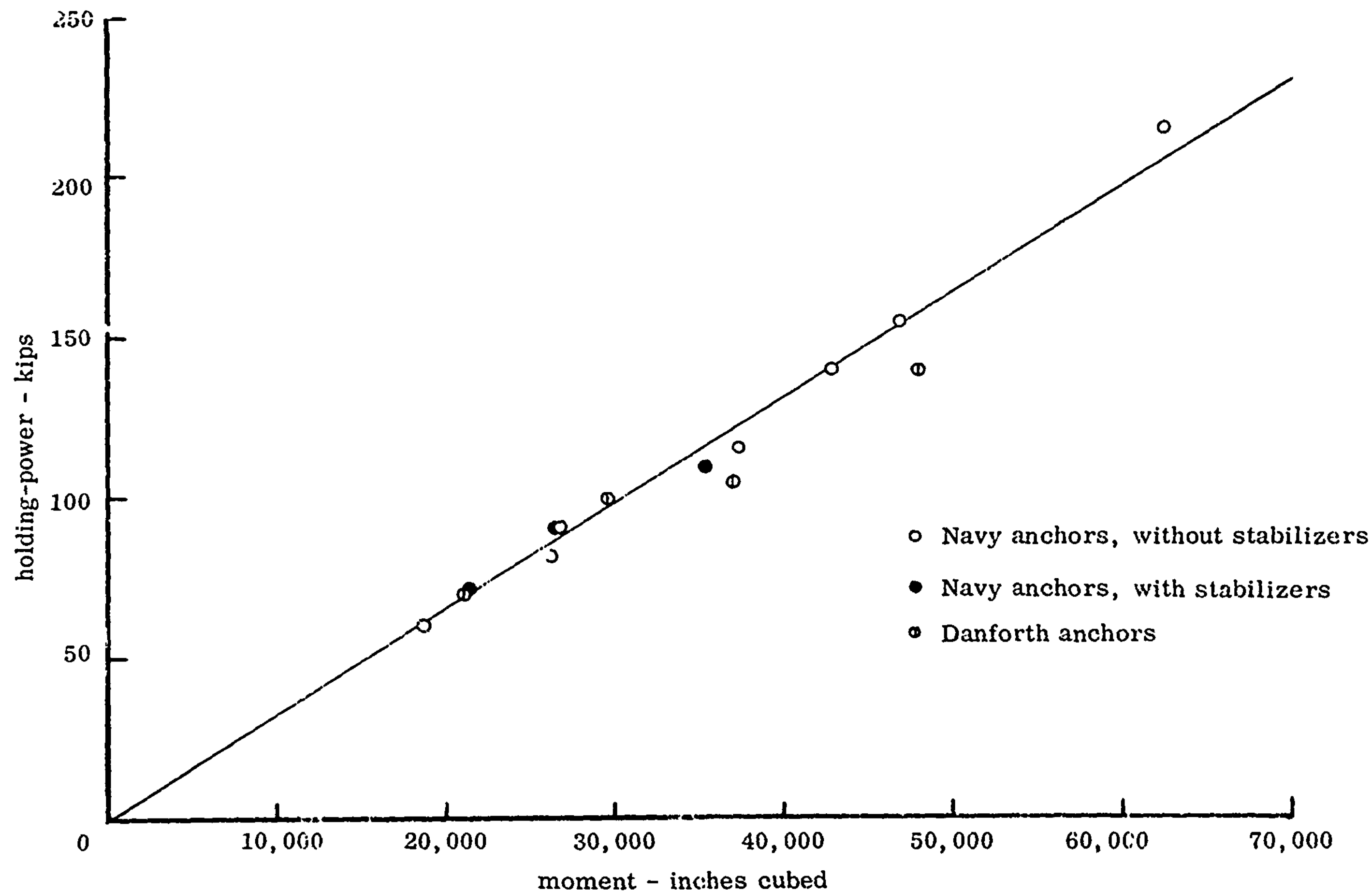


Figure 48. Holding-power vs fluke-area moment.

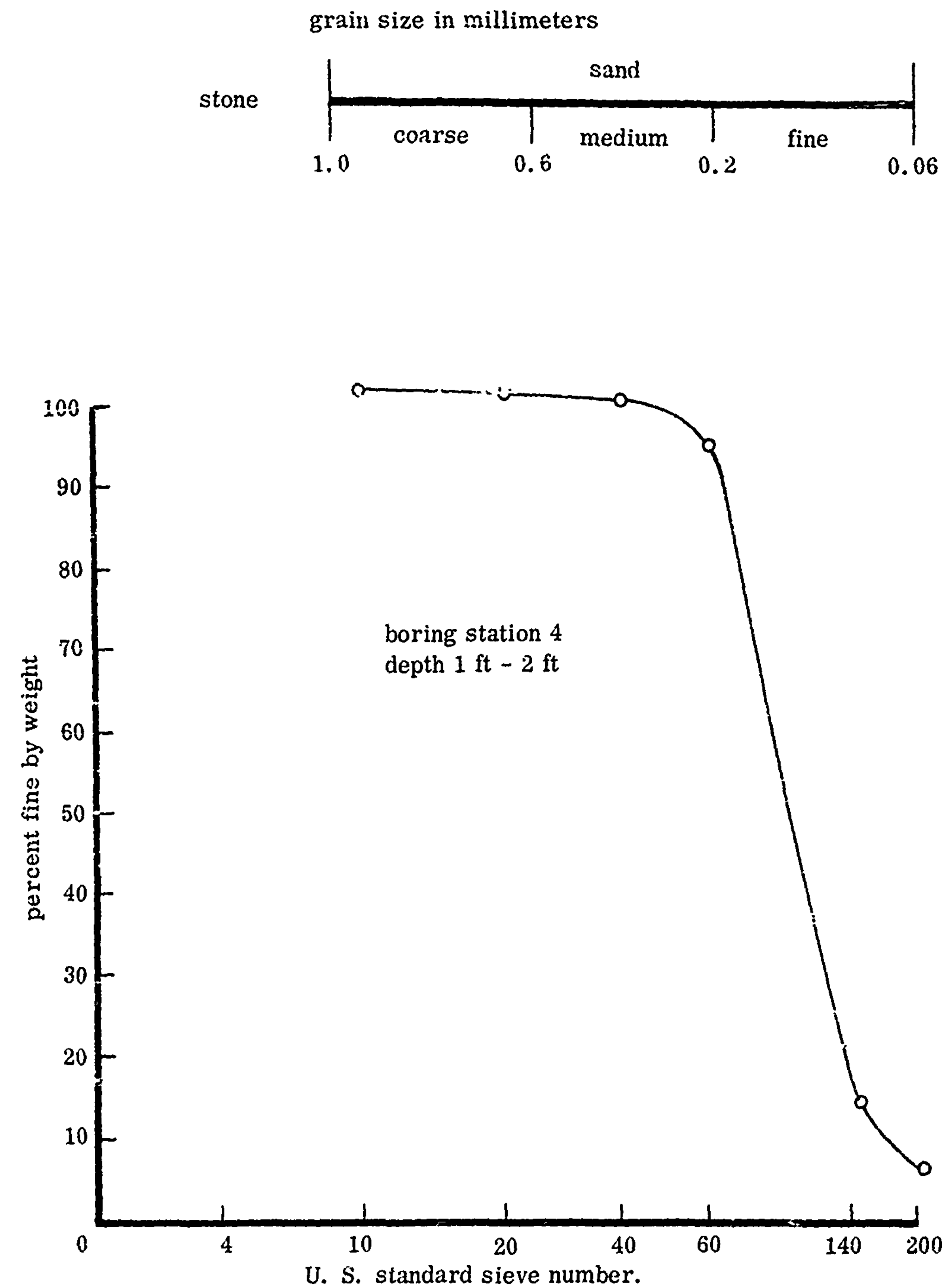


Figure 49. Mech cal soil analysis of fine sand at the test site.

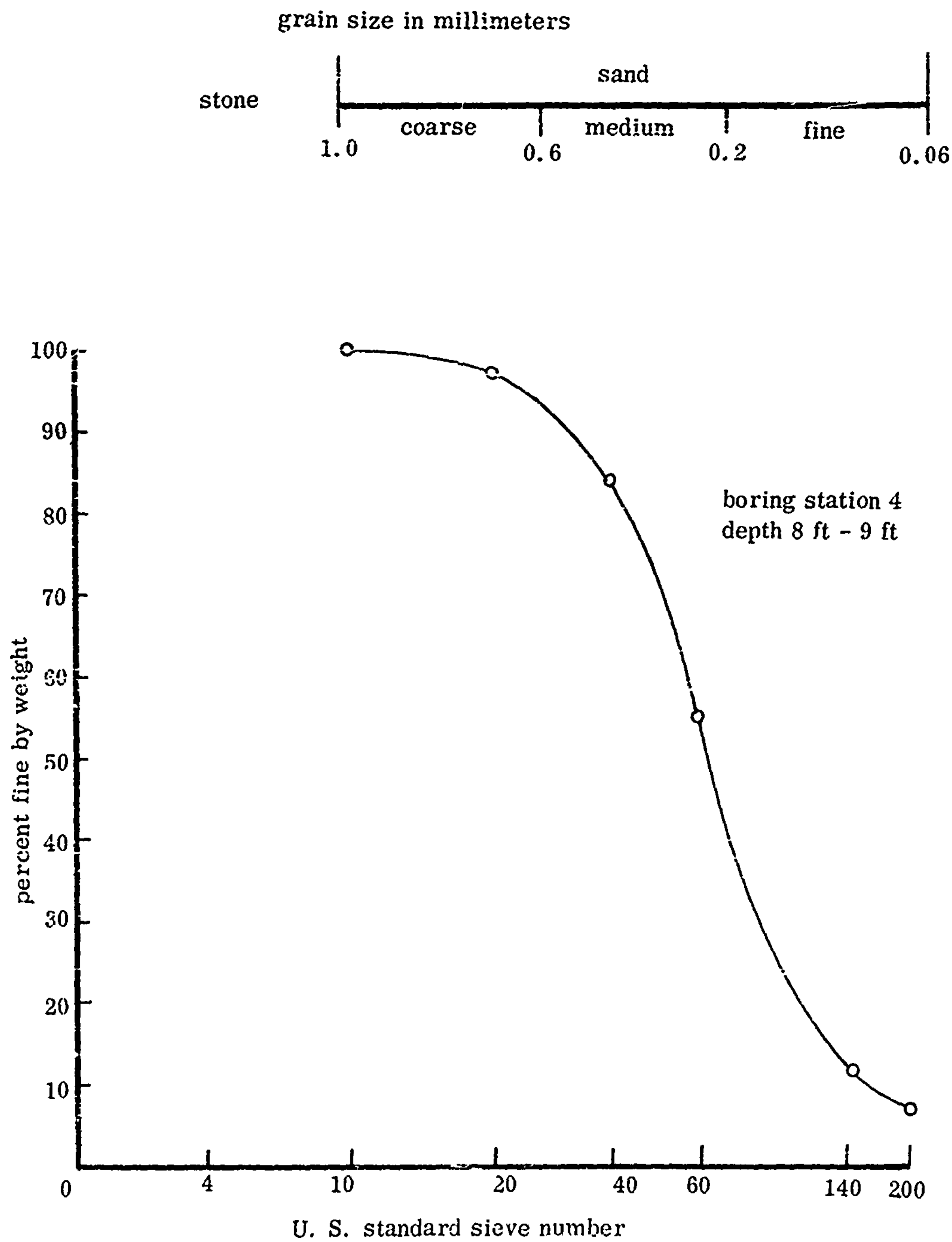


Figure 50. Mechanical soil analysis of medium sand at the test site.

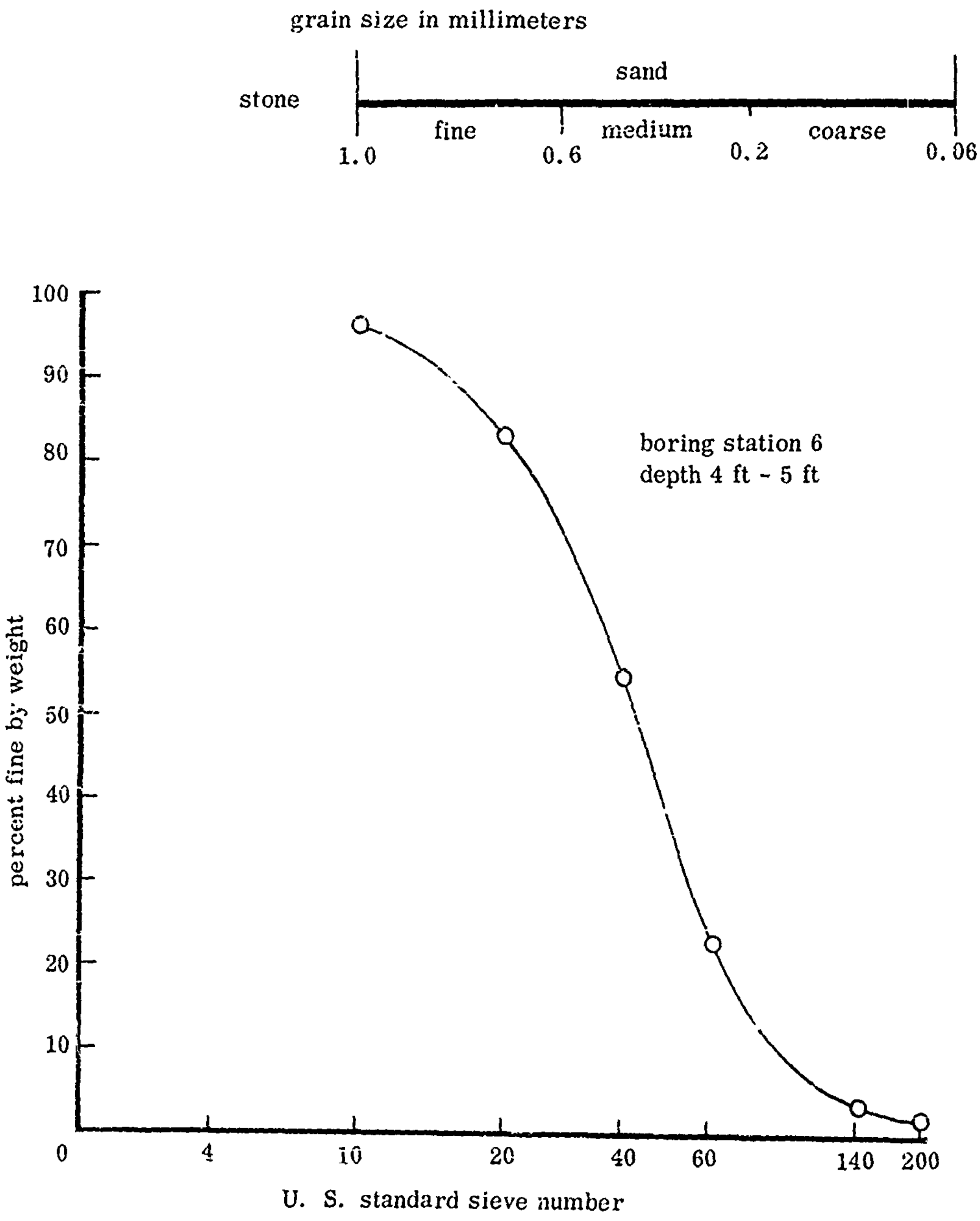


Figure 51. Mechanical soil analysis of coarse sand at the test site.

a cubic foot of sand having a voids ratio of 0.50, the volume of solids is twice the volume of voids, or 2/3 cu foot, and the volume of total voids is 1/3 cu foot. The lower the voids ratio, the greater the unit weight of the soil.

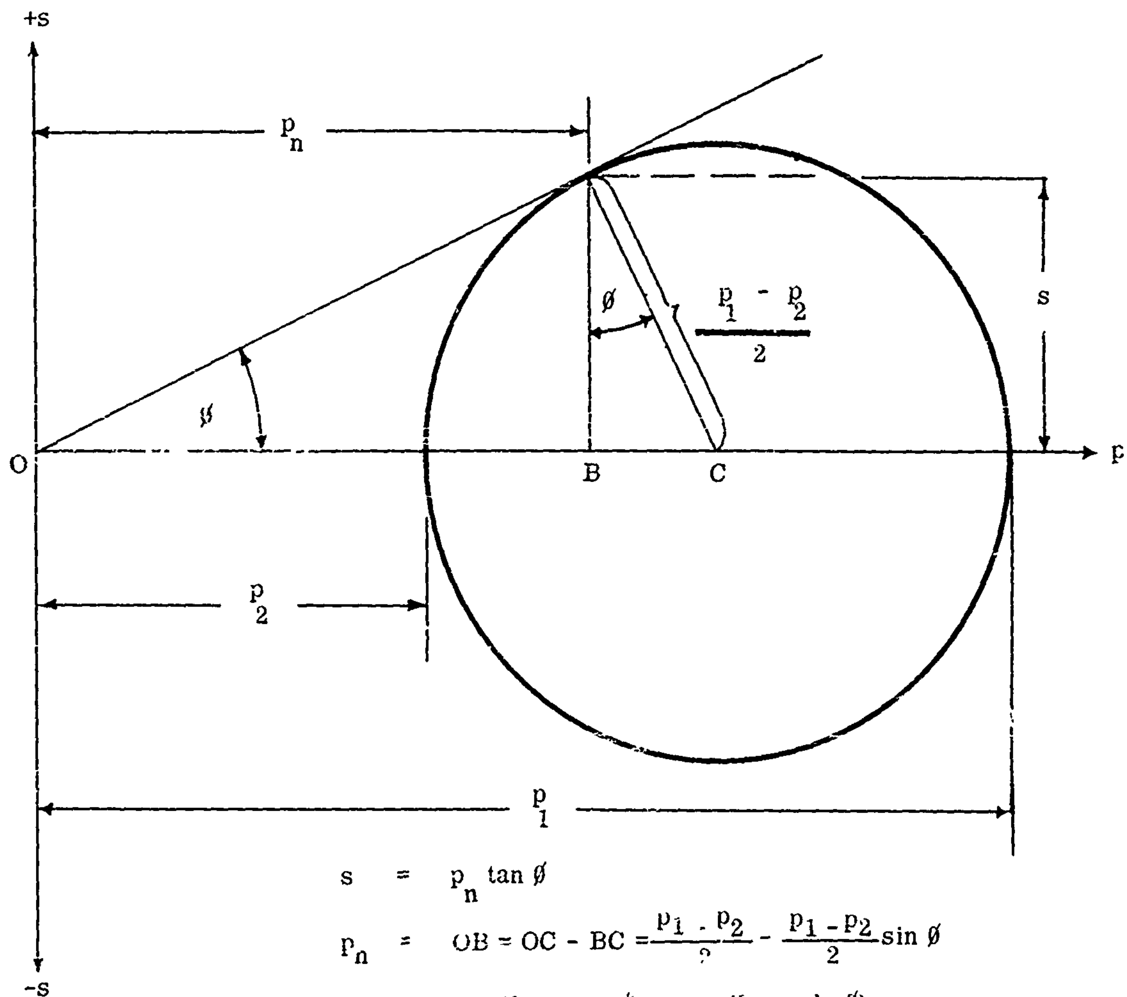
In practically all shearing tests, the sand either bulks or densifies during shear. This volume increase or decrease is determined by two conditions: the initial voids ratio before shearing, and the system of applied load. Since, with sand, the relation between the principal stresses is fixed at any instant and at any given voids ratio during shear, it follows that the volume change during shear is controlled by the initial voids ratio and the magnitude of the minor principal stress during shear.

The relationships between the stresses for the case of axial symmetry is shown in Figure 52; s being the shearing stress on the surface of shear and p_1 and p_2 being the major and minor principal stresses, respectively. This is the well-known Mohr diagram.

If a sample shears at constant volume, the initial voids ratio is the critical voids ratio of the material. To every critical voids ratio, there corresponds a fixed and definite value of minor principal stress, p_2. If the initial voids ratio, e, is below the critical value, the sample bulks during shear, the volume increase being proportional to the extent to which the initial e is below the critical value. If the initial voids ratio is above the critical e, the sample compacts during shear to an extent that is proportional to the difference between the actual initial e and the critical value. At the critical value, the sand shears with neither bulking nor compaction. This is the critical e, or zero line. Figures 53, 54, and 55 show the fine, medium, and coarse sands, respectively.

The angle of internal friction also changes as the sand bulks or compacts. This angle varies within wide limits in the same sand. The relations between the critical e and p_2 are shown in Figures 56, 57, and 58. The relations between the initial e and the angle of internal friction for the fine, medium, and coarse sands, respectively, are further shown in Figures 59, 60, and 61.

A study was made to determine the stress analysis for an anchor being dragged through sand; but, because of the large variable factors in the tests, no precise data could be obtained. However, it is possible



$$s = p_n \tan \phi$$

$$p_n = OB = OC - BC = \frac{p_1 + p_2}{2} - \frac{p_1 - p_2}{2} \sin \phi$$

$$= \frac{p_1 \, (1 - \sin \phi) + p_2 \, (1 + \sin \phi)}{2}$$

or, since

$$p_1 \, (1 - \sin \phi) = p_2 \, (1 + \sin \phi)$$

then

$$p_n = p_2 \, (1 + \sin \phi)$$

so that

$$s = p_2 \, (1 + \sin \phi) \tan \phi$$

Figure 5_. Mohr diagram of cohesionless earth failure.

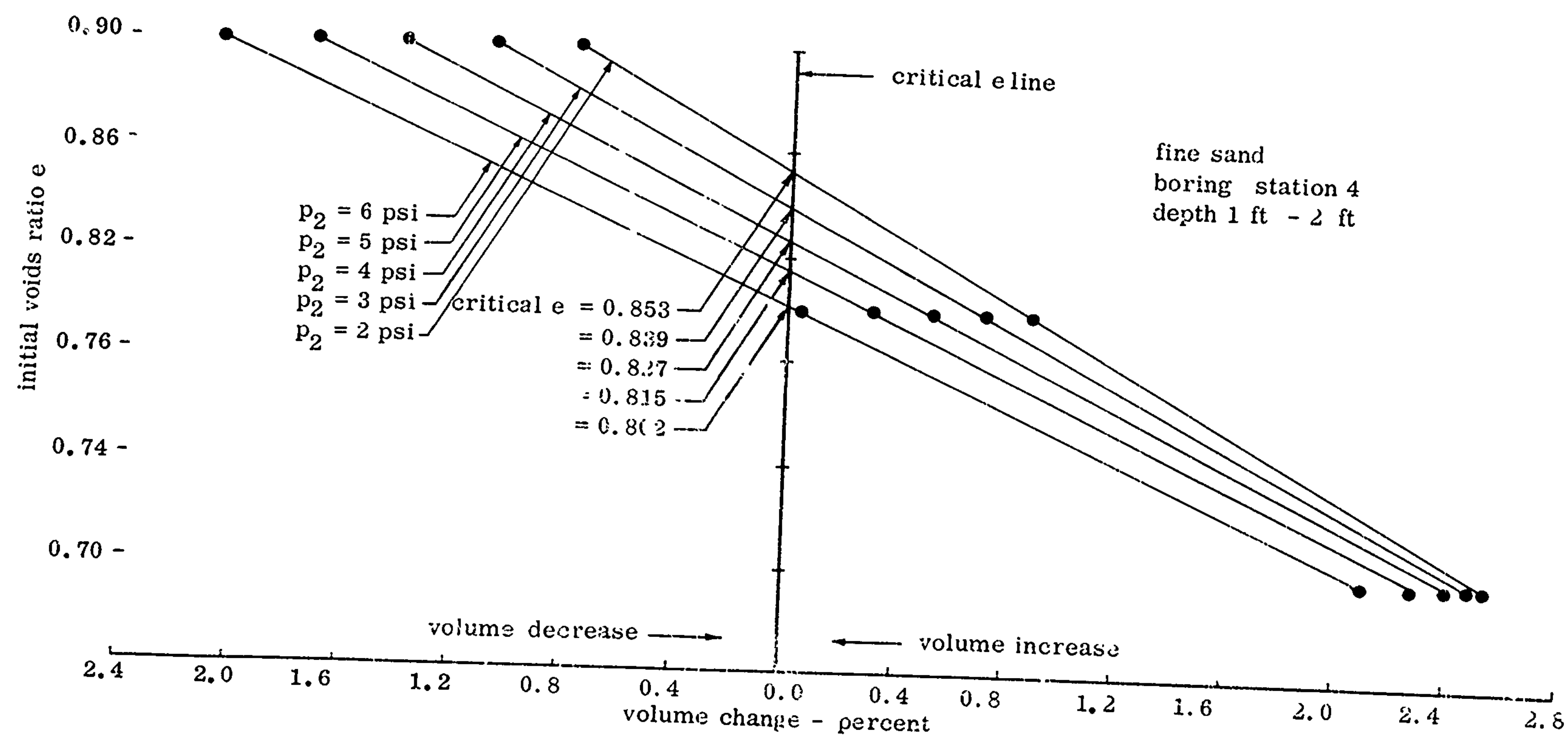


Figure 53. Voids ratio vs volume change for fine sand at the test site.

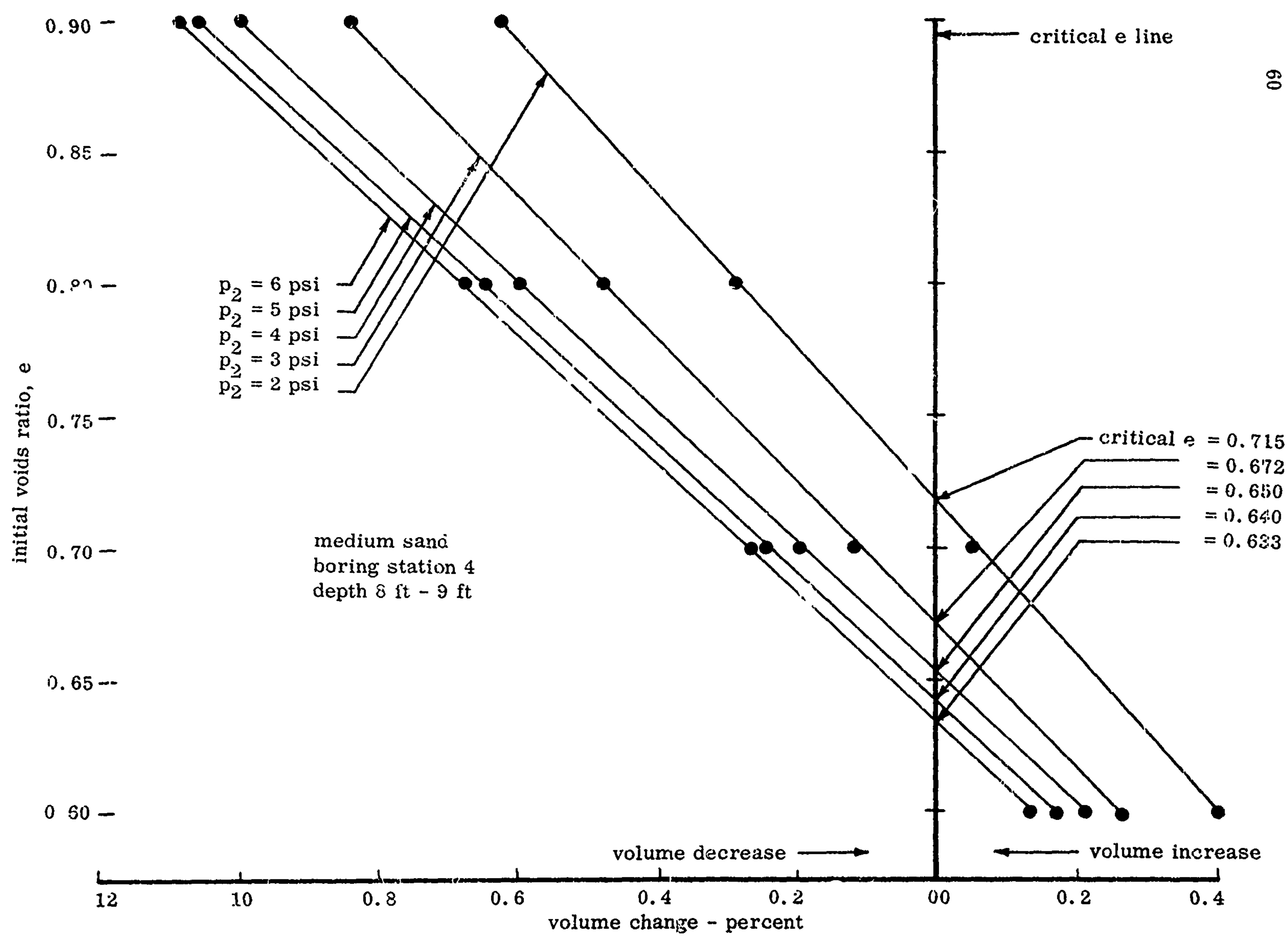


Figure 54. Voids ratio vs volume change for medium sand at the test site.

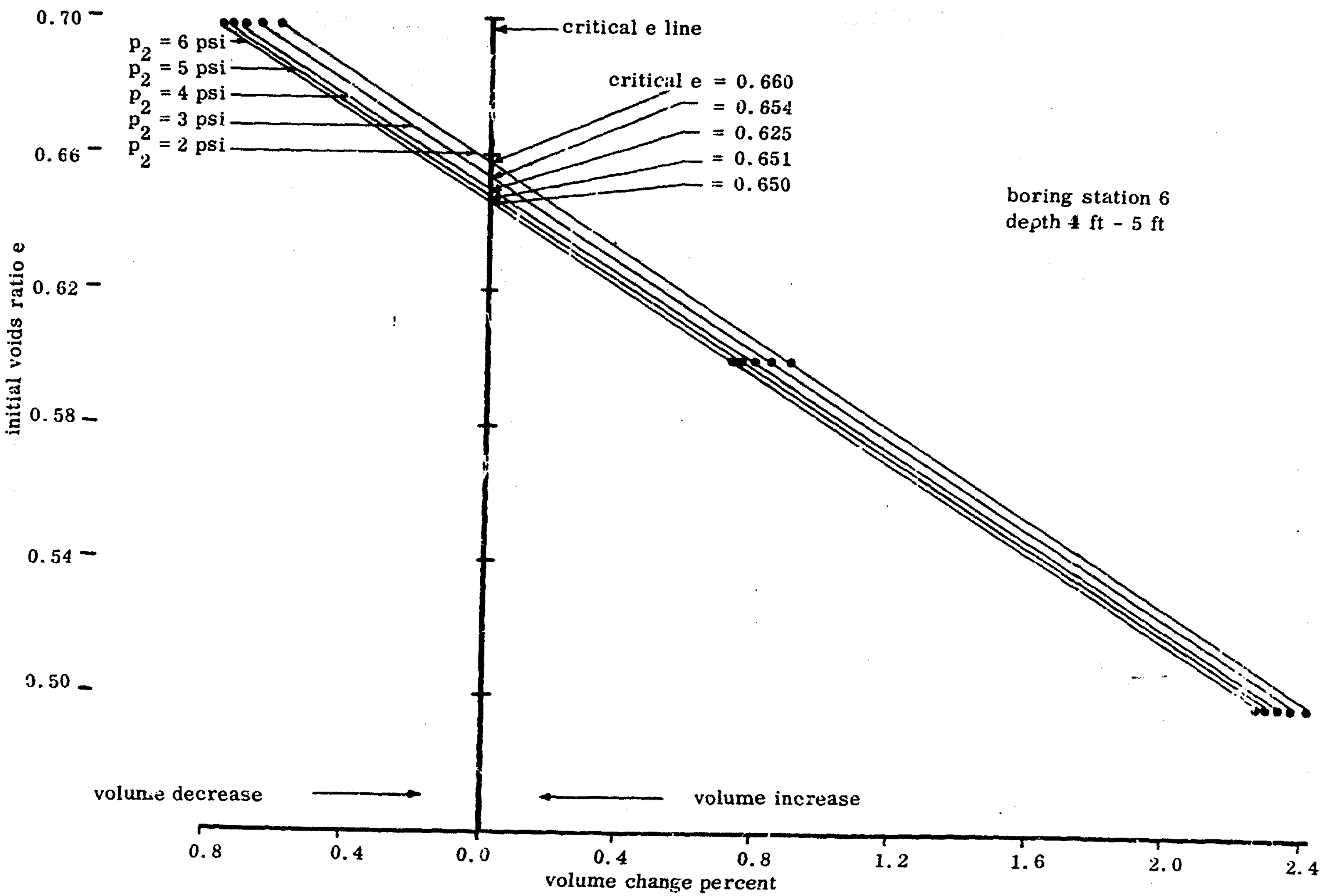


Figure 55. Voids ratio vs volume change for coarse sand at the test site.

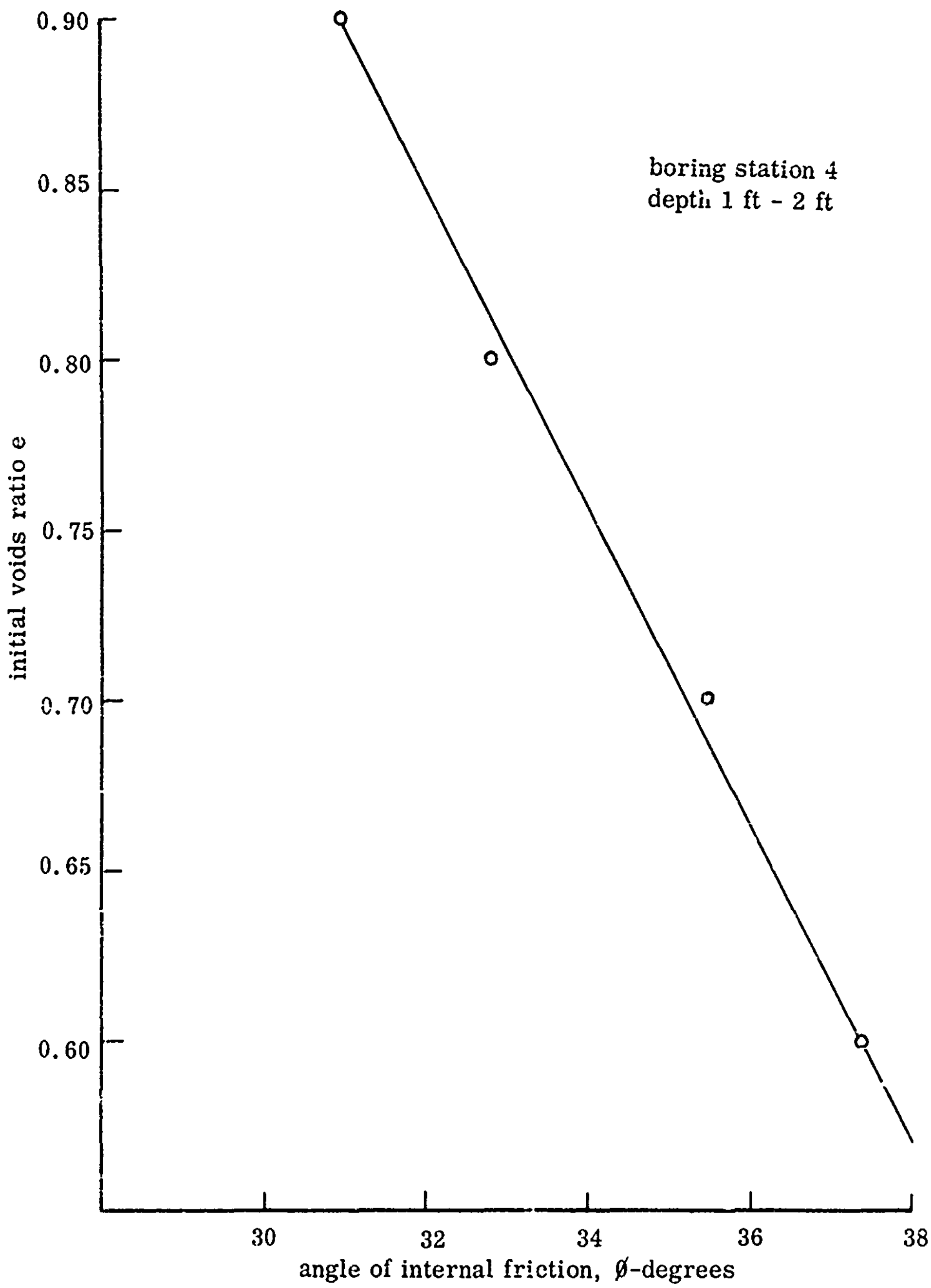


Figure 56. Voids ratio vs angle of internal friction for fine sand at the test site.

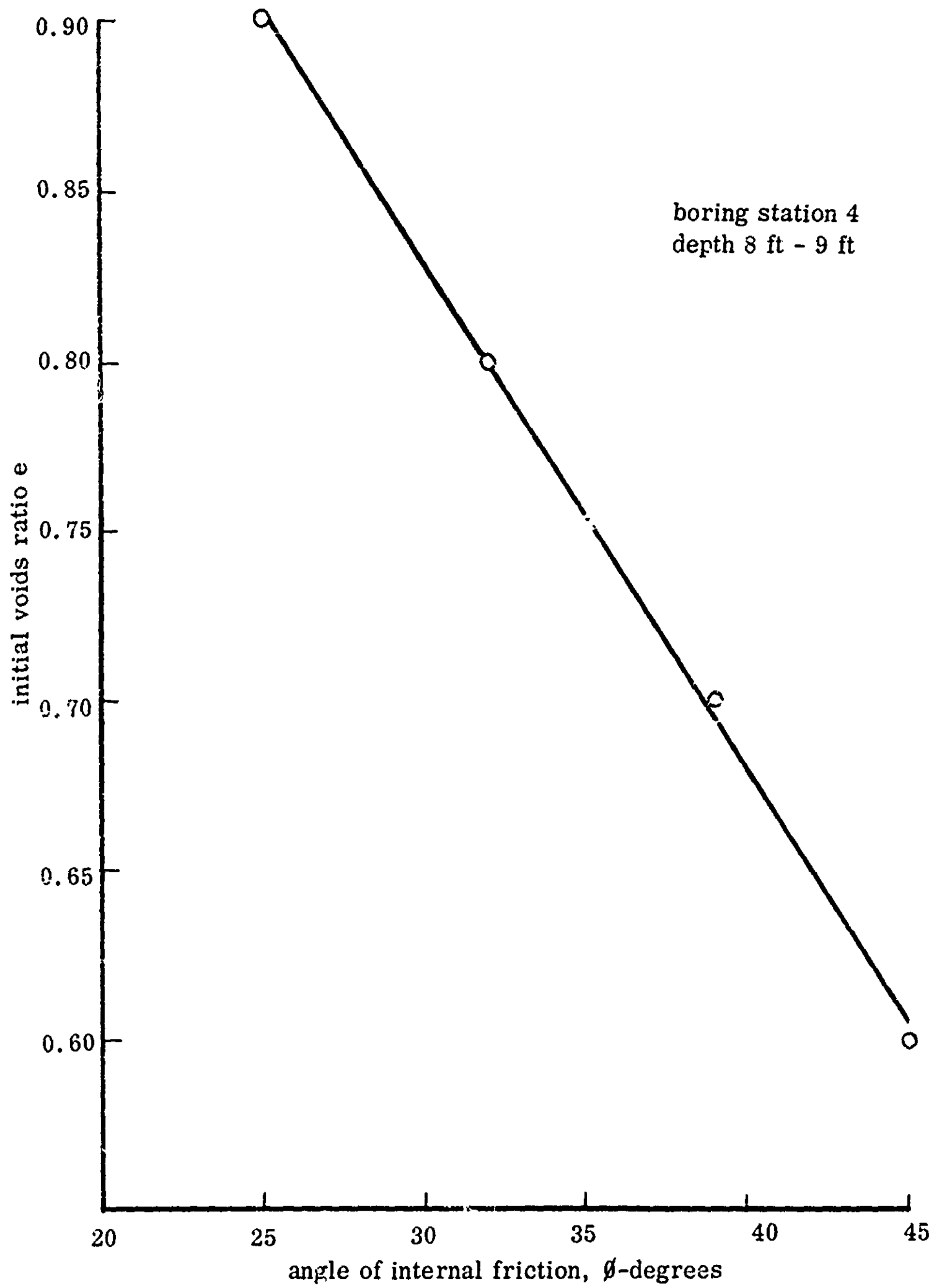


Figure 57. Voids ratio vs angle of internal friction for medium sand ɾ the test site.

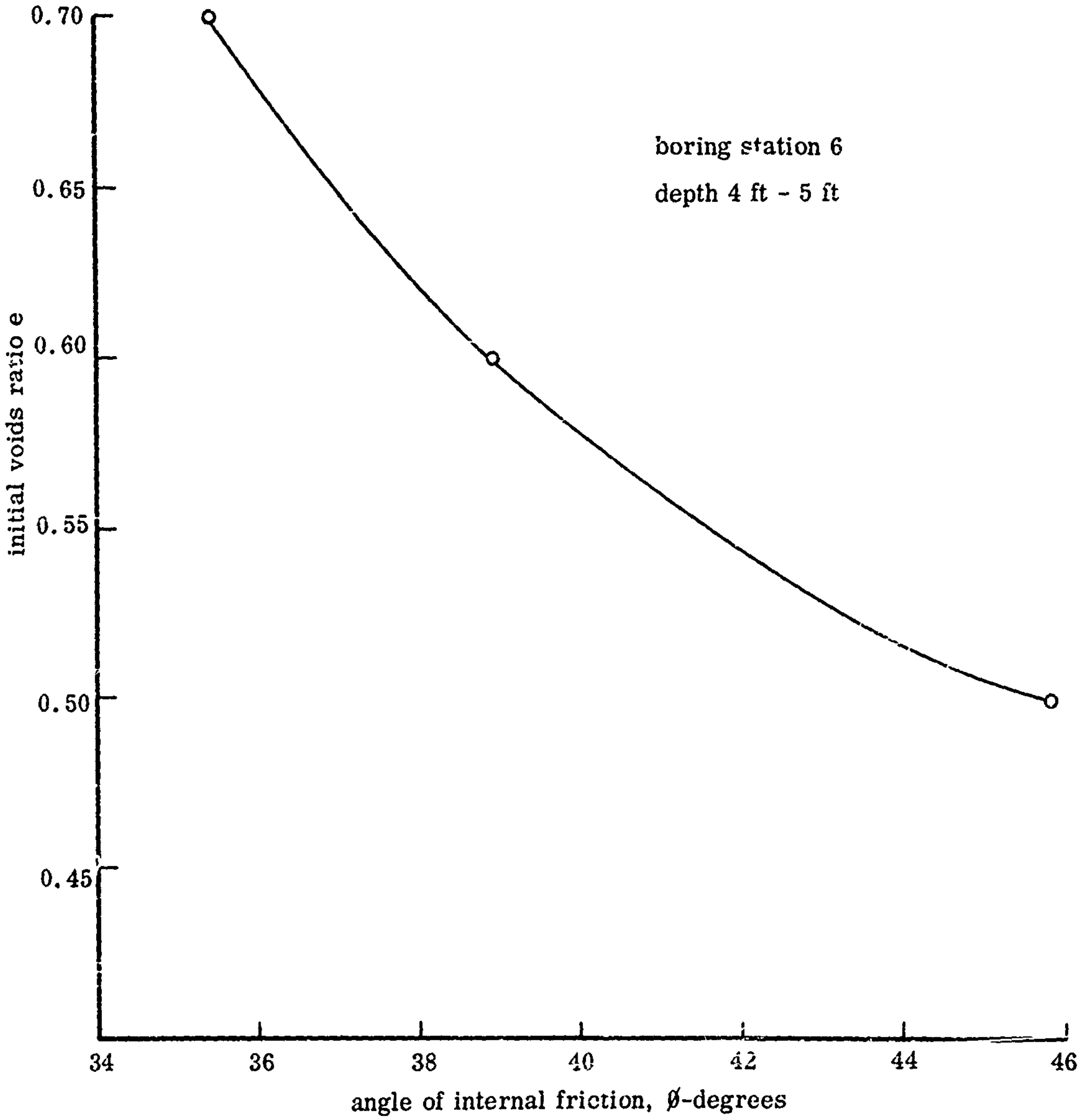


Figure 58. Voids ratio vs angle of internal friction for coarse sand at the test site.

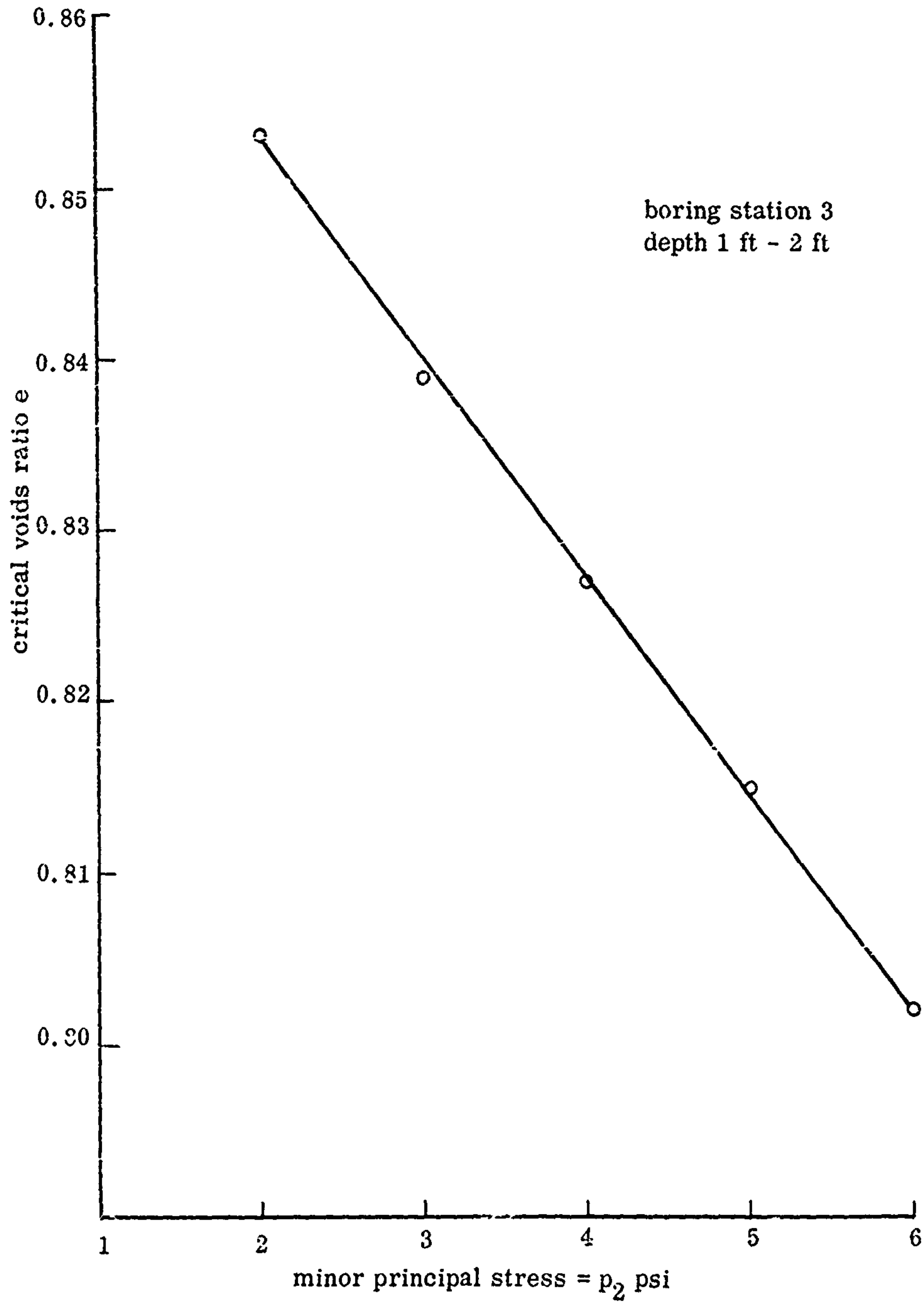


Figure 59. Relation between voids ratio and minor principal stress for fine sand at the test site.

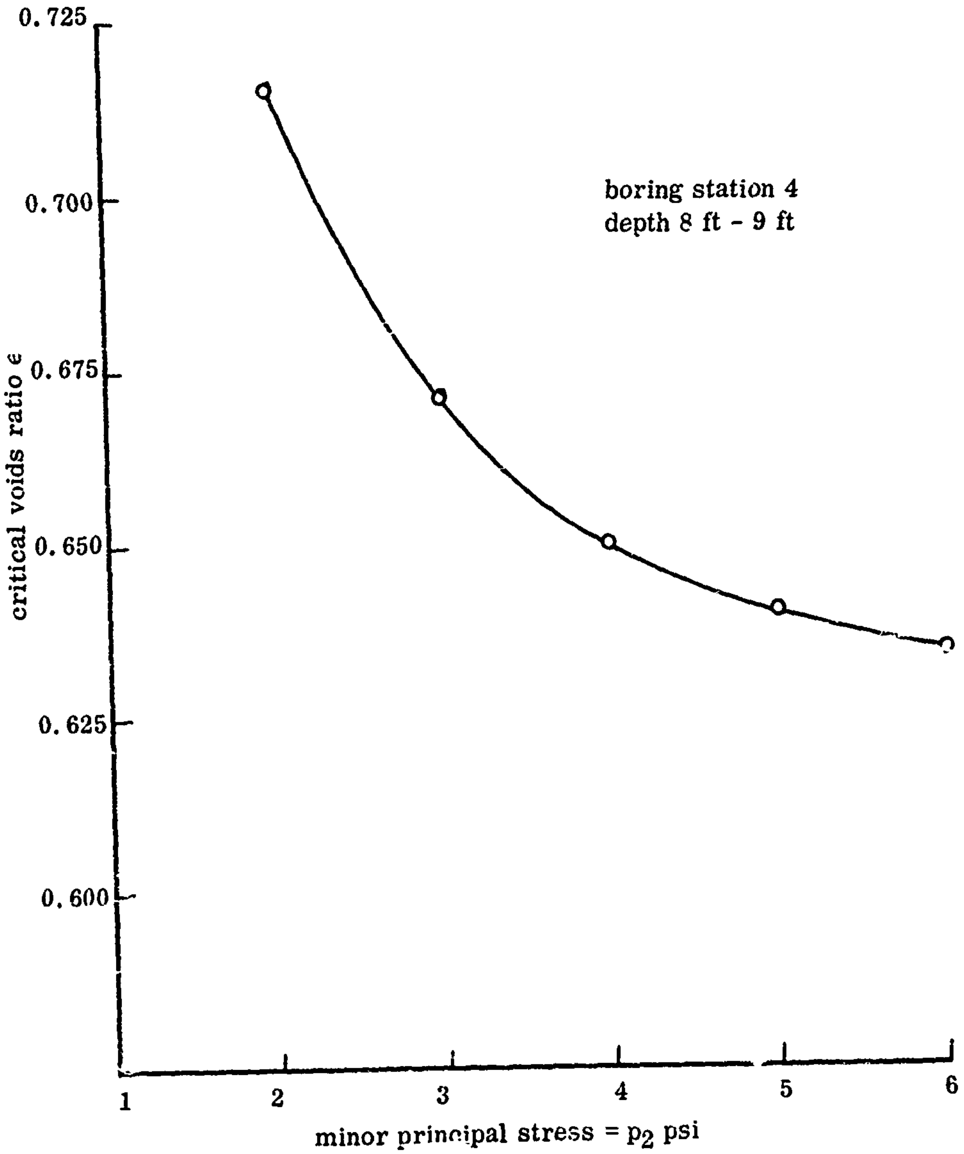


Figure 60. Relation between voids ratio and minor principal stress for medium sand at the test site.

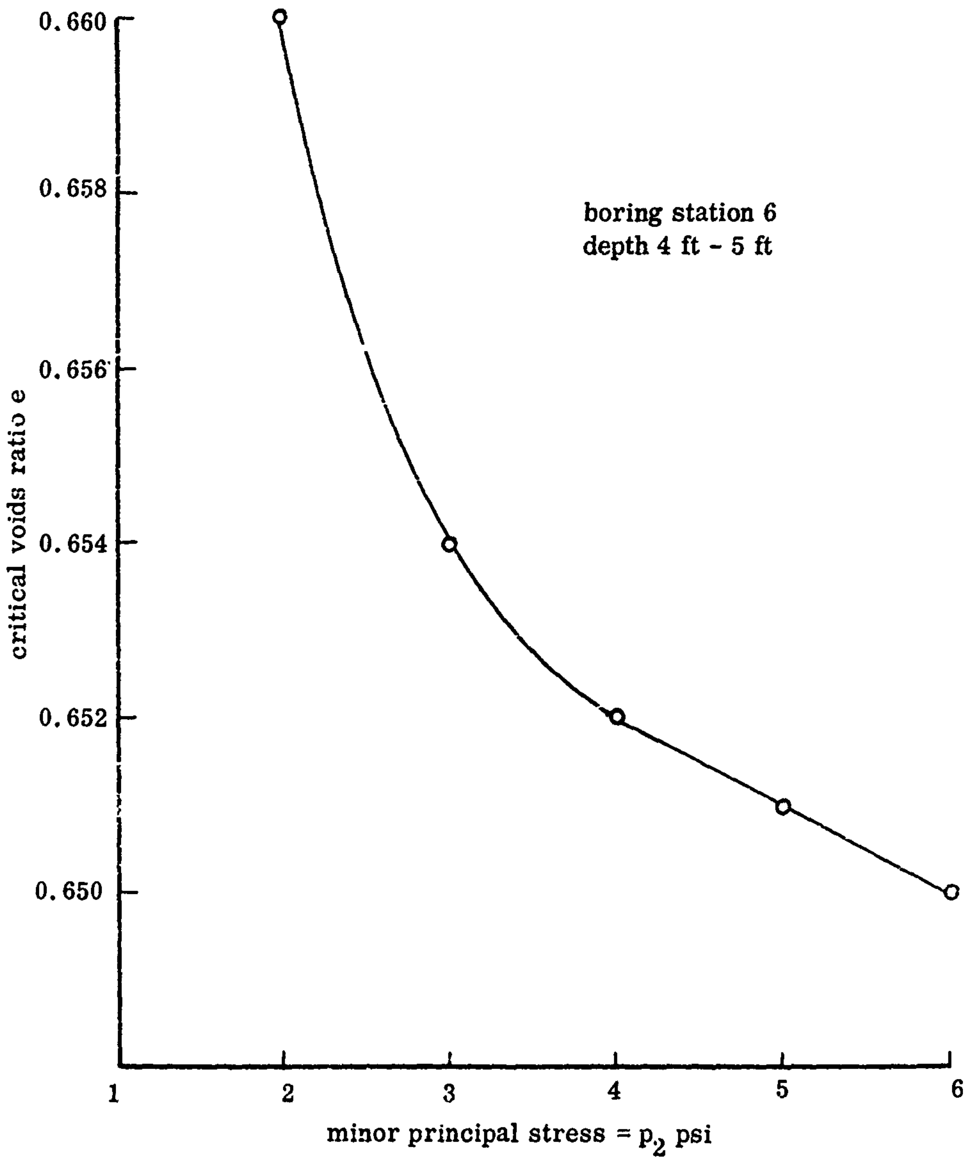


Figure 61. Relation between voids ratio and minor principal stress for coarse sand at the test site.

to obtain some indication of the effect of variations in the sand density on the resistance to anchor pull; that is, with a given anchor and a given sand bottom, how much the resistance to pull may be made to vary by bulking or densifying the sand, keeping all other variable factors such as angle of pull, depth of penetration, etc., constant.

Sand	Initial e	Initial ϕ	Range in e	Range in ϕ
Fine	0.9	30.0	0.3	7.4
Fine	0.6	37.4	- -	- -
Medium	0.9	25.0	0.3	20.0
Medium	0.6	45.0	- -	- -
Coarse	0.7	35.4	0.2	10.4
Coarse	0.5	45.8	- -	- -

The frictional resistance varies more with e in the case of medium and coarse sand than in the case of fine sand. This observation may be true only for the sand in the test area. Also, there is a wider range in initial e variability for fine and medium sands than for coarse sand. This follows because it is easier to densify a cubic foot of loose sand by shaking than to densify a cubic foot of baseballs by shaking.

It is possible that repeated dragging of an anchor over the same route in sand will eventually bring the sand along the path of pull to its critical density corresponding to the minor principal stress developed by the pulling force. That is, if the sand in-place is initially dense, repeated dragging of the anchor will progressively bulk the sand until a limit is reached; and, if the sand in-place is initially loose, repeated anchor pulls will densify it, within a limit. The limit would be the condition of critical density. When this limit is attained, subsequent variations in resistance to pull would be due to variable factors other than the shearing resistance of the sand.

One important property to study, where anchors are dragged in sand bottom, is the relation of critical density to stress, the s corresponding to various initial e values.

From the last equation for s (see Figure 55), the variations in anchor pull caused solely by variations in initial e of the sand are shown in the following table.

Sand	Initial e	Sin ϕ	Tan ϕ	$s = p_2 (1 + \sin \phi) \tan \phi$
Fine	0.9	0.515	0.600	0.91
Fine	0.6	0.607	0.765	1.23
Medium	0.9	0.423	0.466	0.66
Medium	0.6	0.707	1.000	1.71
Coarse	0.7	0.579	0.710	1.12
Coarse	0.5	0.717	1.030	1.77

Example: suppose that p_2 is the weight of submerged sand above the center of area of the surface of an anchor opposed to the line of drag. If the depth is 8 ft in submerged sand p_2 is about 0.5 kips; then:

<u>for the fine sand</u>,

$$s = 0.5 \times 0.91 = 4.55 \text{ k/ft}^2$$

$$\text{or} \quad s = 0.5 \times 1.23 = 6.15 \text{ k/ft}^2$$

depending upon whether the initial voids ratio is 0.90 or 0.60.

s = unit shearing resistance

<u>for the medium sand</u>,

corresponding values for s are:

$$s = 3.30 \text{ k/ft}^2 \text{ or } 8.55 \text{ k/ft}^2$$

depending . whether the initial e is 0.90 or 0.60.

for the coarse sand,

$$s = 5.60\ k/ft^2 \text{ or } 8.85\ k/ft^2$$

depending on whether the initial e is 0.70 or 0.50.

For the medium sand, the percentage increase in s by decreasing e from 0.90 to 0.60 is:

$$\frac{8.55 - 3.30}{3.30} \times 100 = 160 \text{ percent, approximately.}$$

Actually, the increases in total shearing resistance are considerably greater than may be indicated because the surface of shear tends to be increased in area or extent as the voids ratio is decreased and the angle of internal friction increased. It must be remembered that total, and not unit-shearing, resistance is considered, and that the shearing surface has reference to that developed by the anchor.

CONCLUSIONS

The following information is based on results of tests conducted in a sand bottom and does not apply for these or similar anchors under dissimilar types of terrain.

The Navy stockless anchor in its present form will rotate under a strong chain pull, causing a varying holding-power. This characteristic can be corrected by the addition of stabilizers. The size of the stabilizer is based upon the anchor reactions in the ocean bottom.

Addition of stabilizers will increase the holding-power of stockless anchors by approximately 10 percent and, at the same time, provide a more uniform holding-power. With the "fluke-angle" reduced to 35 degrees and the stabilizers attached, the holding-power is increased a total of 34 percent.

The holding-powers of the stockless anchors operating on the beach, averaged 37.7 percent more than the holding-powers of the same anchors operating under water.

Modifying the Navy stockless anchor by welding a steel plate across the flukes does not appreciably increase the holding-power of the anchor, and the holding-power is definitely not increased in proportion to the increase in size of the plate.

As the holding-power of an anchor is proportional to the moment of the projected fluke-area about the ocean bottom, the ratio of holding-power to weight can be increased by eliminating the anchor crown and putting the weight saved into larger fluke-areas with a proportionately longer fluke to increase the moment.

The holding-power of an anchor is affected by the density of the soil through which the anchor is being pulled. Holding-power of anchors, pulled in uniform sand layers with void ratios similar to those found in the three types of sand at the test site, could vary as as much as 160 percent.

The "fluke-angle" of an anchor operating in a sand bottom has a definite effect upon the holding-power. The fluke must bite into the bottom at an angle which will allow the fluke to penetrate rapidly and to a depth which will produce the largest moment or holding-power. A small "fluke-angle" results in rapid penetration but does not produce a large projected fluke-area to resist dragging through the sand. A large "fluke-angle" presents an increased projected fluke-area, but does not permit proper fluke-penetration into the sand bottom. An angle of approximately 35 degrees, as determined in these tests, most nearly fits the demands of both a rapid penetration and a large holding-power.

An anchor chain will add a small amount to the holding-power of an anchor by friction along the bottom, but it is primarily useful in absorbing shock by applying the holding-power of an anchor to the ship in a uniformly increasing rate as the ship pulls on its mooring and the curve in the chain approaches a straight line.

No appreciable advantage was found for a fixed-fluke anchor over a regular anchor with rotating flukes in regard to the distance required to seat the anchor and to reach the anchor's maximum holding-power. An exception to this was the 5000-lb Admiralty anchor which reached its maximum holding-power in approximately half the distance required for the other anchors, but only one fluke could be utilized for holding-power.

Holding-power ratios are computed from the average holding-power of the anchor in water after having been dragged a distance of 50 feet as follows:

1. The ratio of holding-power to weight of the newly designed 7500-lb concrete-steel anchor, 7 to 1, is higher than is that of the present Navy stockless anchors, 5.4 to 1; however, care must be exercised in setting the concrete-steel anchor on the ocean bottom to insure that the anchor is placed right side up for maximum holding-power.

2. The commercial-type anchor manufactured by R. S. Danforth has a greater holding-power than does Navy anchor of equivalent weight with stabilizers by an approximately 2 to 1 ratio. The elimination of the large crown, permitting greater penetration and light-weight construction, gives this type of anchor a superior holding-power ratio in a sand bottom. The 85-lb Danforth anchor held 155 times its own weight, which was the greatest proportional holding-power of any anchor tested. The 3380-lb Danforth anchor held 19.5 times its own weight, which was the highest ratio for the heavier anchors.

The break-out force for the Danforth anchors was naturally higher than that for the Navy anchors because of their greater depth of penetration. The average ratio of break-out force to anchor weight for the Navy anchors and Danforth anchors was 2.8 to 1 and 5.2 to 1, respectively.

3. The ratio of holding-power to weight of the concrete anchors is naturally low, approximately 2 to 1, because penetration into the soil is negligible.

The design criteria for a mooring anchor operating in a sand bottom as determined from these tests would be as follows:

a. Light weight, fabricated from steel-plate.

b. Two flukes which can rotate to a 35-degree angle from the shank. This type of construction is advantageous in that the anchor may be set without regard to a right-side-up position. A trigger plate would be required on the steel-plate flukes to trip the flukes and permit the anchor to dig into the sand. Fluke area of the anchor would depend upon the holding-power required, but the length and width of the flukes would be proportioned to produce the maximum moment or holding-power.

c. Elimination of the large crown to reduce obstructions to penetration to a minimum.

d. Addition of stabilizers to provide a uniform holding-power.

RECOMMENDATIONS

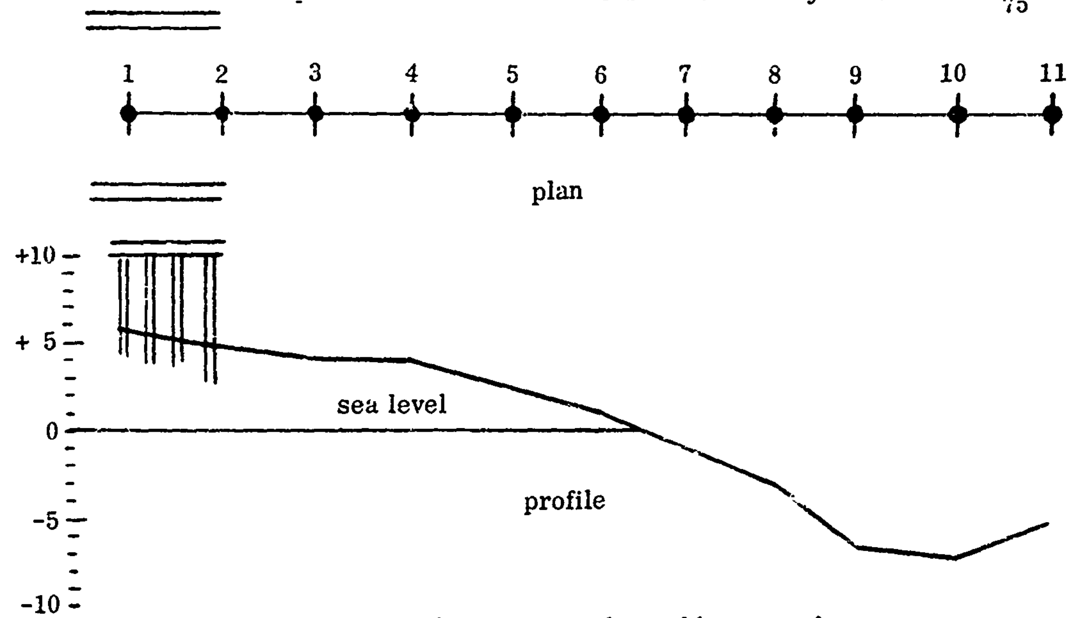
It is recommended that stabilizers be added to Navy stockless anchors which are to be used in moorings or ground tackle in a sand bottom.

Because of the size of the stabilizers and the added shipping cubage involved, the stabilizers should be stored and shipped as separate items from the anchors.

Further tests in a mud bottom should be undertaken to verify the reaction of the stabilizers and to determine the proper "fluke-angle" for operation in this type of soil.

APPENDIX A

Soil-penetration test data - anchor test railway site.



undisturbed soil penetration data - blows per foot

depth - feet	1	2	3	4	5	6	7	8	9	10	11
0-1	5	1	1	3	10	22	3	6	1	18	5
1-2	27	27	14	17	24	52	15	12	3	20	13
2-3	46	54	35	41	34	86	16	6	5	21	30
3-4	95	64	55	62	72	145	16	8	8	46	31
4-5	99	85	90	88	137	170	25	9	18	57	27
5-6	98	88	88	94	181	174	32	19	48	69	32
6-7	81	121	131	141	288	242	58	40	48	69	51
7-8	63	107	119	212	233	235	72	49	55	76	72
8-9	63	94	121	164	216	230	107	59	56	83	74
9-10	91	96	121	132	164	225	122	58	58	55	72
10-11	178	171	215	168	[illegible]	220	143	68	59	64	75

disturbed soil penetration data - blows per foot

depth - feet	1	2	3	4	5	6	7	8	9	10	11
0-1	2	4	4	2	3						
1-2	5	14	17	10	10						
2-3	20	18	26	14	16						
3-4	29	23	35	15	38						
4-5	35	25	40	23	74						
5-6	53	39	73	39	131						
6-7	64	55	109	68	204						
7-8	54	66	130	119	242						
8-9	59	70	144	191	214						
9-10	77	123	155	166	189						
10-11	145	2	181	168	149						
station no.	1	2	3	4	5	6	7	8	9	10	11

APPENDIX B

COMPUTATIONS FOR CHAIN LENGTH

Example:

Maximum holding-power of 18,000-lb anchor, $H = 220{,}000$ lb

Chain = 2-3/4 in. cast steel anchor chain

Weight (lb) of 15-fathom shot of chain in air = $855d^2 = 6466$ lb

d = wire diameter of chain in inches

Weight per foot in air = $855d^2/90 = 71.8$ lb

$$c = H/w$$

$$c = 220{,}000/71.8 = 3064 \text{ ft}$$

since the slope at the anchor is to be zero then the anchor is at point (0, c).

The rise from the anchor to the instrument car = 10 ft therefore, at the upper end of the chain, point (x, y),

$$y = 3064 + 10 = 3074 \text{ ft}$$

now $$y^2 = s^2 - c^2$$

or $$s^2 = y^2 - c^2$$

therefore, at point (x, y) $s = 3074^2 - 3064^2 = 247.7$ ft

Total length of chain required (including 5 ft from bow of car to dynamometer) $247.7 + 5 = 252.7$ ft

Stress in chain at upper end:

$$V = sw = 247.7 \times 71.8 = 17{,}784.9 \text{ lb}$$

$$H = 220{,}000 \text{ lb}$$

APPENDIX C

Bureau of Yards and Docks Addendum to Testing Procedure

SUGGESTED TESTING PROCEDURE FOR DETERMINING SAFE HOLDING-POWER OF CONCRETE ANCHORS, WEDGE- AND MUSHROOM-TYPE

APPENDIX C

Bureau of Yards and Docks Addendum to Testing Procedure

SUGGESTED TESTING PROCEDURE FOR DETERMINING SAFE HOLDING-POWER OF CONCRETE ANCHORS WEDGE- AND MUSHROOM-TYPE

1. Comments on anchors and tests:

(a) BUDOCKS drawing no. 461584 shows a 10,000-lb wedge-type anchor, a 10,000-lb mushroom-type, and a quadruple arrangement of 2500-lb mushroom anchors for test purposes.

(b) The 10,000-lb wedge-type anchor shall be tested for comparative purposes with other concrete anchors. This type has been in use at Pearl Harbor for a number of years, where there is a deep mud bottom.

(c) The mushroom-type anchors, because of their inherent stability, will give a steady pull when dragging is underway.

(d) As shown on BUDOCKS drawing no. 461584, four 2500-lb mushroom anchors are arranged in tandem for testing. The holding-power of arrangement A or B may exceed that of a single 10,000-lb mushroom-type anchor.

2. Tests for holding-power:

(a) The wedge-type, the 10,000 lb mushroom-type, and four 2500-lb mushroom-type anchors in arrangements A and B shown on BUDOCKS drawing no. 461584 shall be tested in sand, clay, and mud bottom. They shall be dragged until the vertical angle of the chain at the anchor end reaches a maximum of 6 degrees ±. In a mud bottom, the tests shall be made as follows:

(1) Immediately upon placing of the anchors.
(2) After placed anchors have settled into the mud for a period of 3 weeks.

(b) A minimum of six runs for each test shall be made and any additional r[illegible] as required in order to determine safe holding-power of the teste[illegible] [illegible]nchor for the type of bottom used.

(c) In order to obtain the required 6 degree ± vertical angle of chain at the anchor ends, suitable chain lengths will have to be found by using estimated or trial holding-power of anchors, known depth of water to anchors, and weight of chain in water.

3. Other requirements with tests:

(a) Test equipment, measurements, soil samples and data sheets shall be required as called for in PGO 13-4a.

(b) Break-out tests will not be required for concrete anchor tests.

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2. BUDOCKS drawing no. 412,751, "Stabilizer Details for Navy Standard Stockless Anchors."

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5. BUDOCKS drawing no. 164,615, "Standard Fleet Moorings - Anchor Details."

6. Pittsburgh Steel Foundry, sheet no. X-4741, "Navy Type Stockless Anchor - 25,000 lb."

7. BUDOCKS drawing no. 461,584, "Moorings - Proposed Concrete Anchors for Testing."

8. Wing-Commander D. F. Lucking, RAF, "The Experimental Development of Anchors for Seaplanes," Transcript of the Institute of Naval Architects, vol. 78, 1936.

9. BUDOCKS Report, Sand Samples, Anchor Tests, Steel and Concrete-Steel Anchors, Soils Laboratory PGO H2-420001 by L. A. Palmer, 5 January 1950.